

# OFFSHORE MARICULTURE ESCAPES GENETIC/ECOLOGICAL ASSESSMENT (OMEGA) MODEL VERSION 1.0

## MODEL OVERVIEW AND USER GUIDE

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# Contents

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List of Figures.....	iii
List of Acronyms and Abbreviations.....	v
<b>Volume I. OMEGA Model Overview.....</b>	<b>1</b>
Introduction.....	1
Project Background and Model Purpose.....	3
OMEGA Information Requirements .....	5
OMEGA Model Components .....	7
Aquaculture Operations Component .....	9
Fish Culture Program .....	10
Escape Scenario .....	13
Interactions Component .....	19
Relative Survival of Escapees .....	20
Encounter Rates.....	22
Fitness and Interactions.....	24
Wild Population Production Component.....	33
Natural Production .....	34
Growth and Maturity.....	34
Harvest.....	35
OMEGA Model Demonstration .....	39
Sablefish Scenario 1: High Escape from Culture Operations .....	39
Sablefish Scenario 2: Low Escapes from Culture Operations .....	44
<b>Volume II. OMEGA User Guide .....</b>	<b>49</b>
About the User Guide.....	51
OMEGA Users.....	51
Software Requirements .....	51
Launching OMEGA .....	51
Macro Security Levels in Excel .....	52
Using OMEGA .....	53
Opening OMEGA.....	53
Adjusting the Viewing Area.....	58
Quick Start.....	59
Using the Scenarios Module.....	71
Working with Scenarios in OMEGA.....	71

Selecting a Species .....	71
Setting a Reference Scenario .....	74
Undo Functions .....	75
Saving Scenarios.....	76
Deleting Scenarios .....	77
Save Results Matrix File .....	78
The Header Section of OMEGA.....	79
Running Calculations in OMEGA.....	80
OMEGA Modules.....	82
Ending an OMEGA Work Session .....	89
Troubleshooting .....	91
References Cited.....	93
Aquaculture Literature Review by Category .....	95
Aquaculture Literature Review by Author .....	110

## Figures

	<b>Page</b>
Figure 1. OMEGA Model Components .....	5
Figure 2. OMEGA Components and Modules Application Map.....	8
Figure 3. Simplified Schematic of OMEGA Aquaculture and Escape Process .....	9
Figure 4. Parameters Specific to the Fish Culture Model and Sablefish Example.....	11
Figure 5. Parameters Specific to Escape Scenario Module and Sablefish Example.....	15
Figure 6. Simplified Schematic of OMEGA Process for Encounter Rates and Survival of Escapees ....	20
Figure 7. Inputs Used to Determine Survival of Escapees, Gametes, and Environmental Factor .....	22
Figure 8. Inputs used to Estimate Wild Population Encounter Rates.....	24
Figure 9. Simplified Schematic of OMEGA Process for Spawning and Genetic Interactions .....	25
Figure 10. Inputs to Describe Reproductive and Genetic Interactions for Sablefish .....	27
Figure 11. Simplified Overview of Single Trait Fitness Model.....	27
Figure 12. Gene flow to Wild Population and Mean Trait Value Change.....	29
Figure 13. Simplified schematic of OMEGA Process for Modeling Natural Production and Harvest .	36
Figure 14. Inputs for Sablefish Natural Production and Growth Parameters .....	37
Figure 15. Inputs for Age-Specific Fishery Selectivity and Maximum Exploitation Rate for Sablefish .....	38
Figure 16. Sablefish Scenario 1—Average Number of Escapes due to Various Factors .....	40
Figure 17. Sablefish Scenario 1—Total Biomass and Percent Biomass of Escapees.....	41
Figure 18. Sablefish Scenario 1—Total Biomass of Females Spawning in Nature and Escapee Spawning Biomass Composition.....	42
Figure 19. Sablefish Scenario 1—Natural Production of Mixed Population Relative to Baseline.....	43
Figure 20. Sablefish Scenario 1—Wild Population Mean Trait Value and Relative Fitness.....	43
Figure 21. Sablefish Scenario 2—Average Number of Escapees due to Various Factors.....	45
Figure 22. Sablefish Scenario 2—Total Biomass and Percent Biomass.....	45
Figure 23. Sablefish Scenario 2—Total Biomass of Females Spawning in Nature.....	46
Figure 24. Sablefish Scenario 2—Natural Production of Mixed Population Relative to Baseline.....	46
Figure 25. Sablefish Scenario 2—Wild Population Mean Trait Value and Relative Fitness.....	47
Figure 26. Enabling Macros in Excel 2010 .....	52
Figure 27. OMEGA Welcome Page .....	53
Figure 28. OMEGA Main Page .....	54
Figure 29. OMEGA Modules Application Map.....	56
Figure 30. OMEGA Main Page .....	57
Figure 31. Scenarios Module.....	60
Figure 32. Load Working Scenario Dialog.....	60
Figure 33. Load Working Scenario Dropdown Menu .....	60
Figure 34. Setting the Reference Scenario .....	61
Figure 35. Selecting a Scenario for the Working Analysis .....	61
Figure 36. OMEGA Results Charts for the Sablefish Scenarios 1 and 2 .....	62
Figure 37. OMEGA Results Shown in Header Chart Figure 1 .....	63
Figure 38. OMEGA Results Shown in Header Chart Figure 2 .....	64
Figure 39. OMEGA Results Shown in Header Chart Figure 3 .....	65

Figure 40. OMEGA Results Shown in Header Chart Figure 4 .....	66
Figure 41. OMEGA Results Shown in Header Chart Figure 5 .....	67
Figure 42. OMEGA Results Shown in Header Chart Figure 6 .....	68
Figure 43. Save Scenario Dialog Box.....	69
Figure 44. Overwrite Scenario Dialog .....	70
Figure 45. Navigating to the Scenarios Module .....	71
Figure 46. Selecting the Change Species Setting in the Scenarios Module .....	72
Figure 47. Changing the Species Setting .....	72
Figure 48. Associating a Scenario with the Selected Species .....	73
Figure 49. Load Working Scenario Dialog.....	73
Figure 50. Undo Functions in the Scenarios Module .....	75
Figure 51. Save Scenario Button.....	76
Figure 52. Saving the Working Scenario .....	77
Figure 53. Overwrite Parameter Values of an Existing Scenario.....	77
Figure 54. Delete Scenario Button .....	78
Figure 55. Delete a Saved Scenario Dialog .....	78
Figure 56. Save Results Matrix File Button.....	79
Figure 57. The Header Section of OMEGA.....	80
Figure 58. Species and Scenario Indicator and Notes Box .....	81
Figure 59. OMEGA Header Chart.....	81
Figure 60. Fish Culture Program Module .....	83
Figure 61. Escape Scenario Module .....	84
Figure 62. Relative Survival of Escapees Module .....	85
Figure 63. Encounter Rate Module.....	85
Figure 64. Natural Production Module.....	86
Figure 65. Natural Growth Parameters Module .....	87
Figure 66. Fitness and Interactions Module.....	87
Figure 67. Harvest Module .....	88
Figure 68. Regulatory Standards/Guidance Module .....	88

## Acronyms and Abbreviations

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1024 x 768	1024 by 768 pixels
BMPs	best management practices
CPU	central processing unit
NOAA	National Oceanic Atmospheric Administration
OMEGA	Offshore Mariculture Escapes Genetic/Ecological Assessment
pHOS	percent Hatchery Origin Spawners (abundance based estimate of percent escapees in natural population)

## **Volume I. OMEGA Model Overview**

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# Introduction

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In June 2011 the United States Department of Commerce (DOC) and National Oceanic Atmospheric Administration (NOAA) published policies for sustainable aquaculture development within the territorial waters of the United States. In addition to issuing permits, and establishing research partnerships, NOAA would be required to develop environmental standards to protect the marine ecosystems in which offshore farms are to be located. One element of these environmental standards is the potential impact escaped farm fish may have on local native stocks and species. The DOC policy states the need to “Ensure agency aquaculture decisions protect wild species and healthy, productive, and resilient coastal and ocean ecosystems, including the protecting of sensitive marine areas”, while the NOAA policy statement under environmental challenges states the need to protect against “potential competitive and genetic effects on wild species.”.

The rapid development of world cage farming of marine fishes has raised concerns over the possible genetic and ecological impact of escaped fish on wild populations. Marine fish can escape from farms for a variety of reasons including, when improper mesh size is used or when holes in webbing develop from normal wear and tear, during transfer from cage to cage or while grading or harvesting fish, from high wind and high sea conditions during severe storms, or when net cages are breached by large predators. Potential effects include the introduction of maladaptive genes and reduced fitness, competition for food and space, and predation on native stocks.

Several factors merit consideration when evaluating the likely ecological and genetic impacts cultured fish may have should they escape. Among them are: the wild population genetic structure and phenotypic variability of a species or among stocks within a species, the size of the local (or affected) population relative to the estimated number and frequency of escapement, the type of breeding program to be used, including selection of the founding stock, and the likelihood that unintentional genetic drift (domestication) related to hatchery practices will occur.

To develop risk assessment and management strategies for open water aquaculture it is important to understand the potential negative impact of farm escapees on their wild cohorts through a review of the scientific literature. In reality there is little evidence-based information available that can reliably assign risk to escapes of finfish from aquaculture facilities; therefore, escape standards are, out of necessity, more preventative than prescriptive. Because of uncertainty, locally adapted indigenous species will probably be encouraged over the use of nonnative and genetically modified species unless a compelling argument can be made that the genetic and ecological risks are demonstrably low.

Because there is a paucity of information in the aquaculture, genetic, or ecological scientific literature on escaped farmed fishes, it is presently difficult to predict the actual impact that escaped fish will have on their wild counterparts within the ecosystem. Some scientific information is available on the intentional release of marine fish species for purposes of stock enhancement. While intentional releases are intended to have a noticeable and positive effect on wild populations of conspecifics by increasing stock size and abundance, effects of accidental escapes are considered to have negative effects (ICES 2002).

Therefore, environmental standards in Canada, the European Union, and Chile, and the United States are aimed at preventing escapes in the first place through production monitoring, engineering of containment systems, best management practices (BMPs), and methods to recover escaped fishes. Because hard scientific

data is lacking, escape standards are qualitative rather than quantitative. NOAA has concluded that proposed environmental standards for the United States will benefit from the use of numerical models, such as OMEGA, to explore the complexities of potential genetic and ecological interactions.

# Project Background and Model Purpose

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The Offshore Mariculture Escapes Genetic/Ecological Assessment (OMEGA) Model was developed by NOAA and ICF International (ICF) as a tool for use by scientists and resource managers to help with understanding the potential negative impact of farmed escapees on their wild counterparts.

The purpose of OMEGA is to identify and weigh environmental risks of escapes of marine aquaculture fish to their wild conspecifics. OMEGA is intended to: 1) provide insights about factors affecting risks associated with escapes from aquaculture operations, 2) help identify research priorities, 3) explore options for the design of sustainable aquaculture programs, and 4) inform policy and management decisions related to the genetic and ecological risks of aquaculture.

In our presentation we refer to fish contained in the aquaculture pens as farm or culture fish, fish that escape from the pens are escapees, and fish that are born in nature are wild fish. OMEGA includes a Natural Production component. This describes the recruitment, survival, growth and age of the wild population. Escapees may not survive to encounter a wild population, so results showing abundance of escapees does not imply all fish will interact with the wild population. Escapees surviving to encounter the wild population are included in the total population abundance and biomass. Spawning abundance and biomass includes escapees adjusted for spawning effectiveness and their wild counterparts. Finally, the abundance of wild fish also includes the offspring of parents that were escapees.

OMEGA allows the user to view changes in population response by varying culture operations and model parameters, and saving them as scenarios. Working in this fashion, the user can observe the sensitivity of population responses to certain combinations of parameters, and visualize whether changes made to the working analysis result in a population response that moves closer to achieving a desired outcome. By evaluating different aquaculture operation scenarios, OMEGA allows the user to compare differences in total abundance trends of escapees and wild fish, as well as the effects of aquaculture program on survival of wild fish. OMEGA simulates a user-defined scenario of aquaculture escapees and their effect on population dynamics of wild conspecifics over a period of 100 years. The abundance, frequency and size of aquaculture fish escaping from an operation is defined by model inputs that specify the number, length of time, and size of fish held in offshore pens, and the likely magnitude and frequency of escapes of farmed fish.

OMEGA defines density-dependent life stages to describe ecological interactions through competition for food and space. Effects of genetic and ecological interactions are calculated under a user-specified set of assumptions. These assumptions define the survival of escapees in nature, their likelihood of encountering conspecifics, the breeding success of escapees, and the consequence of interbreeding on the long-term survival of wild conspecifics. The calculation of loss of fitness in the wild population is based on a phenotypic fitness model described by Ford (2002).

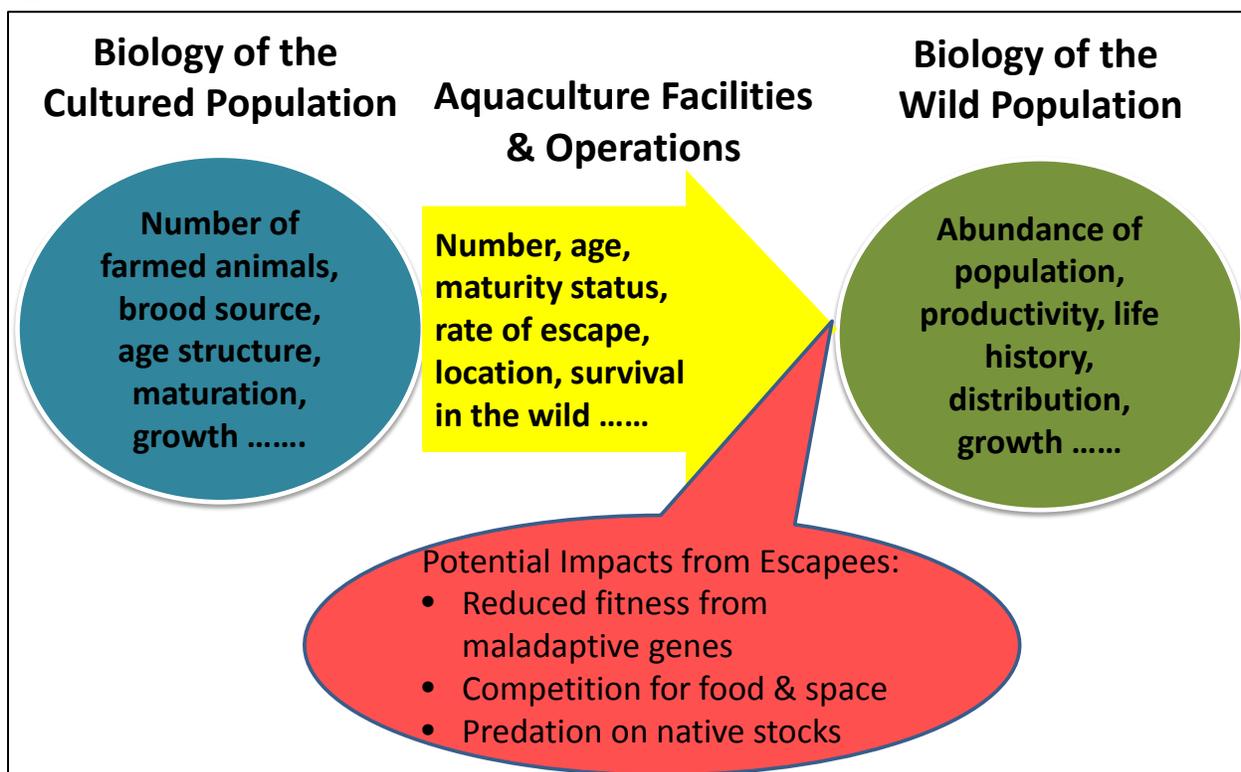


# OMEGA Information Requirements

The OMEGA model is organized around three components (Figure 1):

- aquaculture operation, including assumptions of frequency and magnitude of fish escaping from the pens,
- factors affecting the potential for interaction between farmed fish escapees and their wild conspecifics, including assumptions of survival of escapees in nature, location of the mariculture pens relative to the wild population, potential movement patterns of escapees and breeding success of escapees in nature, and,
- the wild conspecific population, including assumptions of abundance, distribution, survival, age and size at maturity, age composition, and age specific harvest rates.

Figure 1. OMEGA Model Components



Included in each component of the model are modules that describe the specific assumptions used to model potential interactions and impacts of escapees on their wild counterparts. Information necessary to populate the OMEGA model comes from a variety of sources representing knowledge of fish culture and culture operations, population dynamics and behavior of the wild population, and behavior and survival of escaped farmed fish. Ideally, this information can come from direct empirical data, however the reality is information is not available for all components and some will need to come from inferences from other species or from expert judgment. The most problematic assumptions are the lack of data describing the behavior, survival and spawning of escaped farmed fish (Table 1). Some inferences are possible from studies of effectiveness of cultured marine fish for stock enhancement (e.g., Yamashita and Yamada 1999). However, stock

enhancement studies are generally fish cultured to maximize post-release survival and minimize differences between cultured fish and their wild counterparts. It is reasonable to assume that escapees from a domesticated aquaculture stock will behave differently in nature.

**Table 1. Life History Data Sources**

Research Activities	Types of Data				
	Larval survival	Juvenile growth & survival	Post release growth and survival	Contribution to fisheries/ spawning biomass	Dispersal & migration
Stock Enhancement	X	X	X	X	X
Commercial Aquaculture	X	X	- O -	- O -	x
Laboratory physiology	X	x	- O -	- O -	- O -
Fisheries sampling	- O -	- O -	X	X	X

X – data rich, X – some information, x – data poor, and -O- little or no information

# OMEGA Model Components

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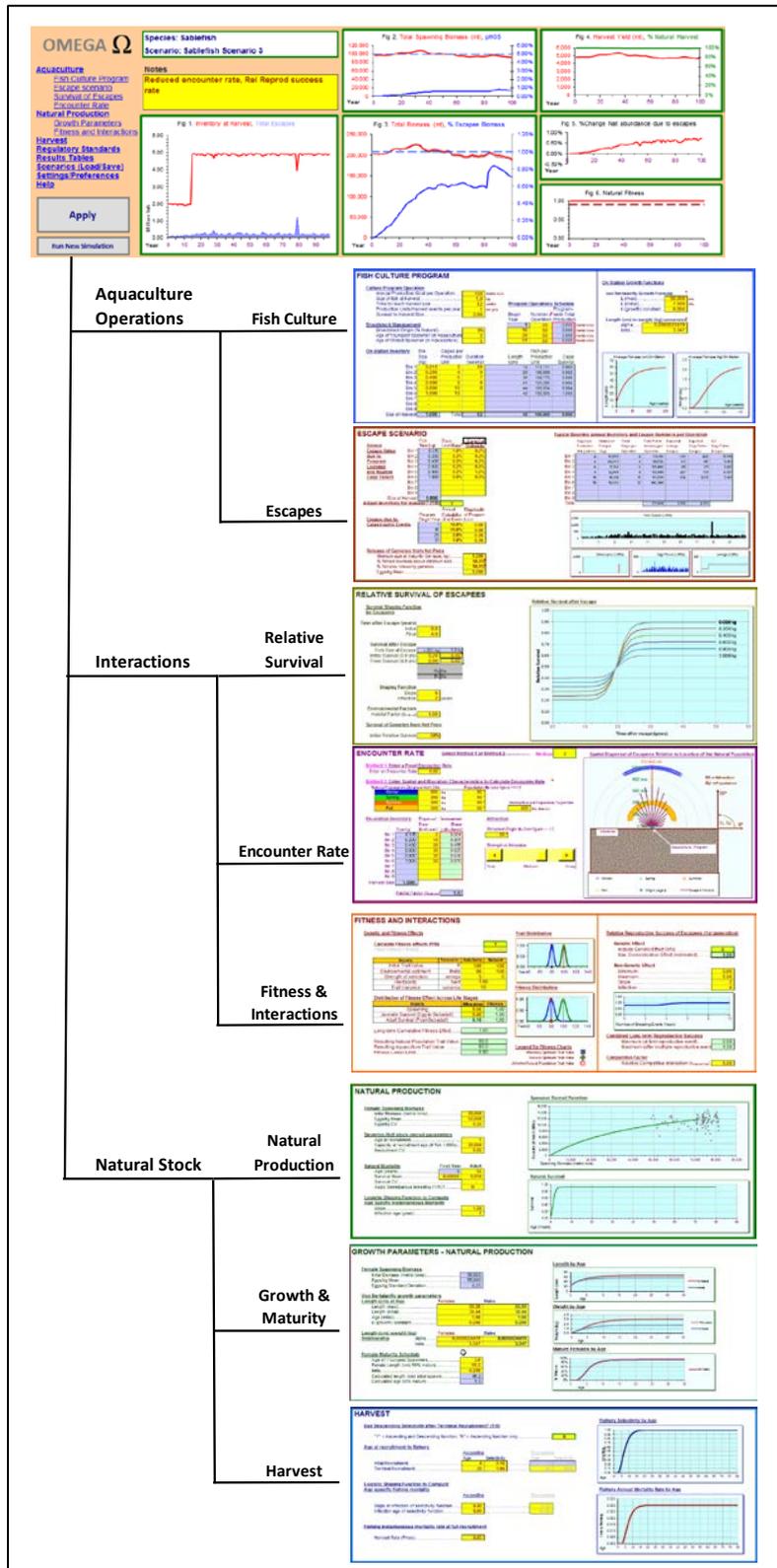
The following is an overview of each component of the OMEGA model and modules within each component (Figure 2). This overview uses a hypothetical commercial aquaculture operation for sablefish (*Anoplopoma fimbria*) along the coast of Washington, Oregon, and California. The distributed OMEGA model includes two scenarios for sablefish. The scenario datasets included with the model were developed to test the model characteristics, sensitivity to assumptions, and to demonstrate the model capabilities. In other words, the scenarios are not intended to reflect a proposed total production or an assessment of likely escapes from such an industry and should not be interpreted as an evaluation of potential impacts from a sablefish mariculture industry.

However, the sablefish example is particularly interesting because the wild population is large. Sablefish are intensively managed by the Pacific Fishery Management Council and as such, information on life history and population dynamics is readily available (Schirripa 2007). The culture of sablefish has long been of interest (Kennedy 1972), and just recently culture methods have been developed to allow the spawning and cultivation of sablefish to harvestable size (Rust pers. comm.). The high value of sablefish and the development of culture methods have promoted an increasing interest in the commercial culture of sablefish in Canada. However, concerns have been raised over the environmental, ecological, and genetic implications of sablefish culture (Robichaud et al. 2004; Sumaila et al. 2005).

Sablefish along the West Coast (Washington, Oregon, and California) are managed as a single stock (Schirripa 2007), and commercial harvest of sablefish extends back 100 years. West Coast sablefish landings were at historic highs in the 1970s, exceeding 24,000 metric tons (mt) in 1976 and 1979. Concerns over long-term sustainability of the stock have resulted in fisheries regulations that have reduced the harvest such that recent annual catch of West Coast sablefish has ranged from approximately 5,000 to 6,000 mt (2003 to 2006). The female spawning biomass has been stable in recent years ranging from approximately 76,000 to 94,000 mt for the period 1997 to 2007. West Coast sablefish reach maturity at approximately 6 years of age and are long-lived. Maximum age has been reported to exceed 80 years, but generally fish older than 75 years are rare. Parameters for recruitment, maturity, growth, and annual fishery harvest rates used in OMEGA were from Schirripa (2007).

The following sections describe the modules and analytical steps in a simulation for each component starting with a description of the aquaculture operations.

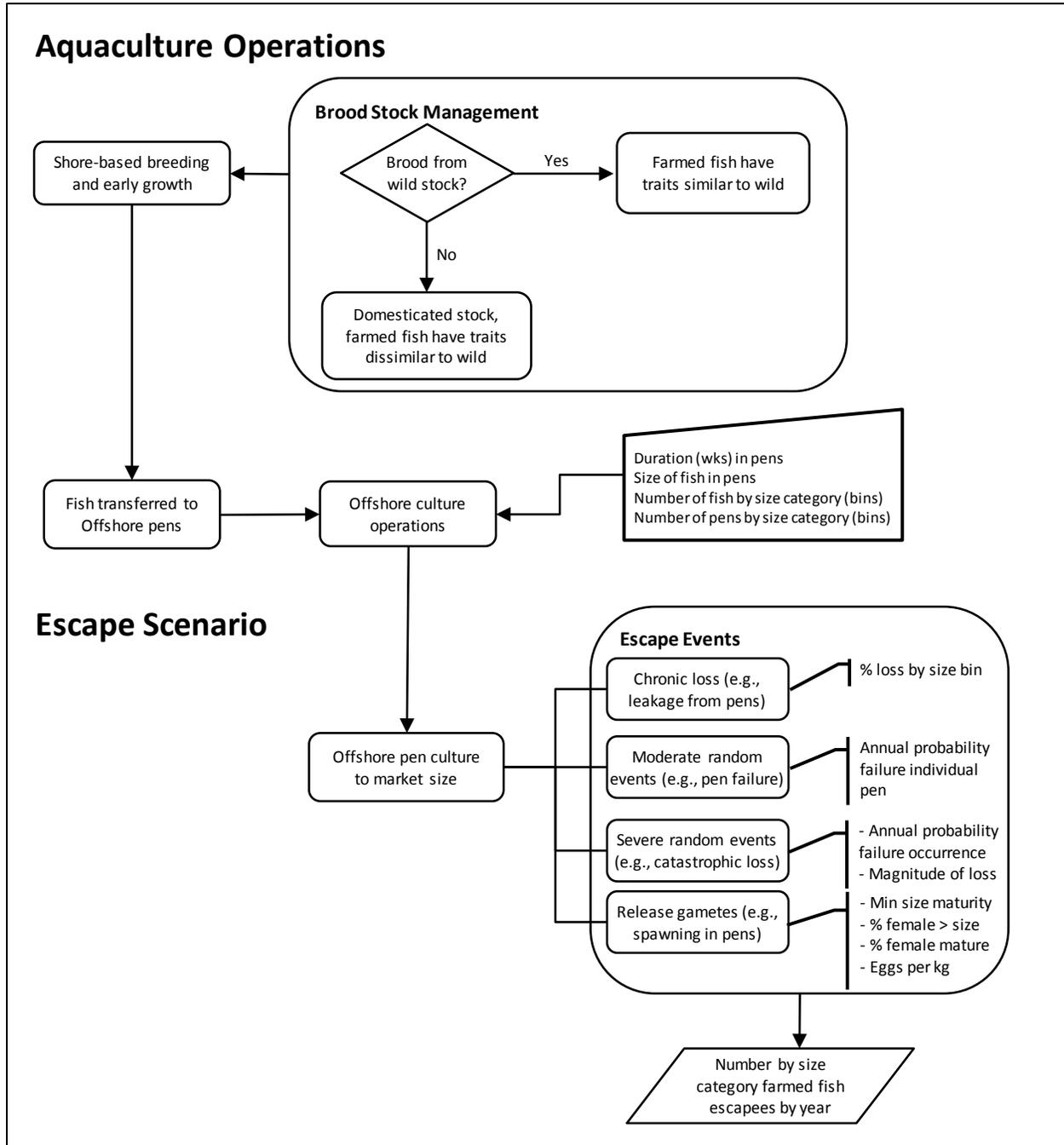
Figure 2. OMEGA Components and Modules Application Map



# Aquaculture Operations Component

The aquaculture component includes modules to describe fish mariculture operations, number of operations, amount of fish produced per operation, and escape assumptions per operation (chronic escapes and two types of random escape events) (Figure 3). Together, these describe the size of the aquaculture operation and a profile of escape occurrences arising from a variety of events specific to growing fish in offshore pens.

**Figure 3. Simplified Schematic of OMEGA Aquaculture and Escape Process**



## Fish Culture Program

This module describes size and abundance of fish transferred to pens, brood stock source, on-station inventory and growth, and operations schedule.

An OMEGA simulation may be based on a single mariculture operation or may include multiple operations with a similar profile (fish culture and escape events). Furthermore, the number of operations can vary over the 100-year simulation period to allow to explore the consequence of an initial startup period when there may be few operations, but a high incidence of escapes, leading to an eventual mature aquaculture industry comprised of multiple operations, but with a lower incidence of escapes per operation.

Specific inputs for each section of the fish culture module are described in the following sections and inputs for the sablefish example summarized in Figure 4.

## Fish Culture Program/Operations

The Aquaculture Operations module profiles a representative operation. This profile includes annual production/harvest goal per operation, size of fish at harvest, total length of time fish are held in net pens, and survival of fish from transfer to offshore pens to harvest.

A description of each input parameter is as follows:

- **Annual Production Goal per Operation:** Annual harvest goal for the operation (metric tons of fish)
- **Production Units/Harvest Events per Year:** The number of production events is the number of times fish are harvested in a year. This is equivalent to the number of times small fish are transferred to pens in a year. Multiple production units imply that fish on station are of different size classes at any given time.
- **Size of Fish at Harvest:** Average size of fish at harvest (kilograms [kg])
- **Time to Achieve Harvest Size:** The total length of time fish are held in pens from transfer to harvest (number of weeks)
- **Survival in Pens:** Cumulative survival of fish in the pen operation (survival from transfer to pens to harvest).

The sablefish example is comprised of 50 operations with each operation producing 200 mt of sablefish for market. Sablefish grow rapidly in culture and are thought to achieve market size of 1.0 kg (just under 50 cm in length) in approximately one year in pens. The market size is on the lower end of the range of sablefish caught in the west coast commercial fishery (Schirripa 2007). Wild fish do not reach the same size until 4 to 5 years of age.

In the example fish are transferred to the pens at 0.015 kg, which equates to approximately 15 centimeters (cm) in length based on an assumed length-weight relationship for sablefish taken from Schirripa (2007). Assumed size at transfer to pens, growth in pens, and size at harvest were provided by Mike Rust and Ken Masee (pers. comm. 2011). The number of size categories (bins) and number of cages/pens in each category are based on a discussion of how operations may occur and growth rates in pens.



## Brood Stock Source

Brood stock source is an option to characterize brood origin in the case that culture operations utilize brood stock sourced from the wild population. This input is the percent of brood stock comprised of wild fish.

An additional parameter requirement necessary to trait cultured fish trait in the phenotypic fitness model is the age structure of the aquaculture brood stock. The aquaculture brood stock age profile is used to determine the generation length of the cultured brood stock and the rate of domestication that may occur in the brood stock over the simulation period. Age at spawning of fish sourced from the wild population is assumed to follow the maturity schedule assumed for the wild population.

Input parameters are as follows:

- **Brood Stock Origin:** Percent of aquaculture brood stock sourced from wild population in each year.
- **Age of Youngest and Oldest Spawner (Aquaculture origin):** This describes the ages (years) of fish spawned originating from the aquaculture brood stock source.

In the sablefish example brood is sourced entirely from the cultured population. Furthermore, the example assumes that these fish reach maturity at a younger age (age 2) compared to their wild counterparts and are kept for brood stock only to age 5. Hence the cultured brood stock has a much shorter generation time than the wild population.

## Program Operations Schedule

OMEGA was configured simulate the effects of a single aquaculture operation or multiple operations of a similar profile. Included in the model is the option to “schedule” the number of operations over the 100-year simulation period.

Input parameters are as follows:

- **Begin Year and Number of Operations:** The begin year defines the period (years) for each operation period. Number of operations defines the number of operations in the simulation for each period. A zero value removes all aquaculture operations for the period, escapes in nature from the previous period remain in the wild population.

As previously mentioned the example assumes 50 operations each producing 200 mt for the entire 100-year simulation period. Total sablefish production (harvest) across all operations equals 10,000 mt.

## On-station Inventory

On-station inventory describes the mean size (kg) of fish in the net pens by size class, the number of fish in each size class, cumulative time fish are in the net pens and in each size class (used only to compute survival rate for a size class), and number of cages/net pens in each size class. The on-station inventory is divided into size classes (bins) to represent the growth profile in-culture and possible differences in escape probability by size class.

Input parameters are as follows:

- **Size of Fish:** Average fish weight (kg) binned by size class. This represents a growth profile of fish held in net pens.

- **Number of Fish by Bin per Production Unit:** A calculated value based on overall survival and length of time fish are in each size bin. This is for a production unit. The total number of fish in a size bin across all operations is the number of fish multiplied by the number of Production/Harvest events in a year.
- **Number of Cages/Pens by Bin Class per Production Unit:** The number of cages or net pens used to hold fish in each size class (bin). This is for a single production unit. The total number of cages/pens in a size bin is the number multiplied by the number of Production/Harvest events in a year.
- **Bin Duration:** The number of weeks fish are in each size bin.
- **Bin Survival:** Survival in each size bin calculated based on the cumulative on-station survival and number of weeks fish are in a bin. For simplicity, survival is assumed to be uniform over time in the pens.

The sablefish example assumes a fairly high survival (90%) in the pens. The consequence is the difference between number of fish transferred to the pens and number of fish at market size is not that great. If survival were lower in the pens than more fish would be transferred to the pens and the number of small fish in pens would be higher leading to the potential for more small fish escaping. The example assumes the number of cages/pens increases with increasing fish size. At harvest the 100,000 fish are assumed to be distributed over 10 cages.

The sablefish example assumes a single production unit/harvest each year. In other words, the operation has a single transfer of fish annually and all fish in pens are the same size/age class at any given time in the year. This has implications when modeling random escape events as will be discussed in the section describing escape scenario.

## On-Station Growth Functions

A von Bertalanffy growth function and length-weight conversion is included to describe growth assumptions for cultured fish in the pens. These functions are used to help set size of fish in pens and the duration (weeks) in each size category.

Input parameters are as follows:

- **von Bertalanffy Growth Formula:** The maximum and initial size of fish on-station (cm), and the von Bertalanffy growth constant (k). Age is weeks.

$$L = L_{Max} + (L_{Initial} - L_{Max})e^{-ka}$$

- **Length (cm) to Weight (kg) Conversion:** Alpha and beta parameters for the length to weight conversion power function:

$$W = aL^b$$

The length to weight conversion parameters for sablefish are from Schirripa (2007) for West Coast sablefish and the growth parameters are approximate assuming a 15 cm (0.015 kg) to 50 cm (1.0 kg) growth pattern over 52 weeks.

## Escape Scenario

The escape module of this component describes the potential for escapes for a single marine pen operation. The OMEGA simulation assumes this profile is representative of all operations in the simulation. Escapes are characterized as originating from four sources:

- chronic losses such as fish escaping through "leakage" from improperly sized net or small holes,
- moderate random events such as fish escaping from "cage failures" caused by equipment failure, boat collisions, and accidents during hauling or cleaning,
- severe random events such as catastrophic failure affecting multiple nets as would occur during a storms resulting in the major failure of the pen structures, and
- eggs or larvae entering the water column from fish spawning in the pens (e.g., Jorstad et al. 2008).

The chronic loss rate is modeled as a percent of fish in the pens escaping. These escapes can represent the difference between initial inventory and final inventory minus mortality and estimates of fish lost due to predation.

A moderate random event (cage failure) is the probability that a cage will fail in a year. The OMEGA model assumes all fish in the cage escape in the event of a cage failure. The number of cages in the simulation affects the number of cage failures and number of escapes due to cage failure. Increasing the number of cages will increase the number of cage failures, but reduce the number of fish lost at each occurrence. Conversely, reducing the number of cages will decrease the number of occurrences, but each occurrence will result in more fish escaping. The consequence is assuming few cages results in a high interannual variability in escapes from cage failure.

A severe random event is an assumed catastrophic failure resulting in a loss of some proportion of fish in pens. Severe random events include an assumption of annual probability of an event and assumption of magnitude of loss. A catastrophic failure results in the escape of fish on-station at the time of the event. In the sablefish example, fish are all the same size any given time in the year (i.e., a single production unit). OMEGA randomly selects a size bin for each operation and production unit to apply the catastrophic loss if occurred in year. The OMEGA simulation assumes a severe random event affects all operations.

Fish escapes due to chronic loss, moderate random events, and from fish spawning in pens are not varied over the 100-year simulation period. In contrast, OMEGA includes the ability to vary the probability and magnitude of loss from severe random events over the simulation period. This option was included to account for how an industry may develop improved structures and techniques over time to reduce the occurrence of escape events (see Moe et al. 2007 for a discussion of Atlantic cod escapes and experiences as that industry was developed). The example included with the model includes variation in severe events at different points during the sablefish simulation (e.g., higher probability and magnitude of escapes early in the simulation).

The consequence of including probabilities and randomization for moderate and severe events is simulation results will vary when running OMEGA with randomization. Thus, the example analysis for sablefish presented in the Model Demonstration section of this report includes multiple simulations with randomization to explore effects of timing and frequency of events on the number of escapees entering the wild population and effect on survival and abundance of the wild population.

Specific inputs for each section of the escape scenario are described in the following sections and the sablefish example is summarized in Figure 5.

**Figure 5. Parameters Specific to Escape Scenario Module and Sablefish Example**

<b>Escape Scenario</b>		<b>Base Leak rate</b>	<b>Cage Failure Probability</b>
	<b>Fish size class</b>		
	<b>Bin 1 - 0.015 kg</b>	3.0%	0.5%
	<b>Bin 2 - 0.2 kg</b>	1.0%	0.5%
	<b>Bin 3 - 0.4 kg</b>	0.5%	0.5%
	<b>Bin 4 - 0.6 kg</b>	0.5%	0.5%
	<b>Bin 5 - 0.8 kg</b>	0.5%	1.0%
	<b>Bin 6 - 1 kg</b>		1.0%
	<b>Adjust Inventory for Leakage:</b>		Y
	<b>Catastrophic failures:</b>	<b>Annual probability event</b>	<b>Magnitude of event</b>
	<b>Years 1 to 15</b>	10.0%	0.60
	<b>Years 16 to 25</b>	5.0%	0.40
	<b>Years 26 to 50</b>	5.0%	0.20
	<b>Years 51 to 100</b>	5.0%	0.20
<u>Gamete release from Pens:</u>			
<b>Minimum size spawning:</b>	1.2	kg	
<b>% females abv min size gametes:</b>	25%		
<b>Potential gametes released:</b>	0		

## Chronic Loss—Escapes due to Leakage

Escapes from leakage can be attributed to improperly sized mesh, a higher incidence of small fish in the inventory, and from fish escaping through small holes in the net caused by wear and tear. The sablefish example assumes leakage is highest with small fish compared to large fish. The assumption is that improperly sized mesh and small holes will allow more escapes of small fish than large fish. In part these assumptions were based on unpublished data from a small experimental study of coho, Chinook and steelhead (Mahnken unpublished data). This study showed a pattern of higher unknown loss (the difference between initial and final inventory minus mortalities) in small coho compared to larger fish held in pens.

OMEGA has the option to adjust inventory based on assumptions of chronic loss. The number of fish transferred to pens is recalculated to account for escaped fish to still achieve harvest objectives.

Input parameters for chronic loss (leakage) are as follows:

- **Escapes from Leakage:** The percent of fish by size bin in each pen escaping. The percent is applied to the number of fish at the beginning abundance of fish in the size bin.
- **Adjust inventory for Leakage:** This assume that leakage is accounted for in the inventory management and additional fish are transferred to the pen to account for "losses" due to leakage.

Chronic loss in the sablefish example assumes a higher leakage with smaller fish. The example does not include chronic loss applied to fish at harvest size (1.0 kg). The last size bin is intended to describe the activity of removing fish from the pens for harvest and, thus is assumed to be a single point in time that would not experience losses due to leakage.

## Moderate Random Events—Escapes due to Cage Failure

Moderate random events are escapes from failure of individual pens or cages. Inventory is not adjusted for cage failure losses. Thus, inventory at harvest is reduced when cage failure occurs in a year. A high incidence in cage failure may result in a substantial decrease in number of fish harvested from the aquaculture operation. Cage failures also reduce the number of fish assumed to escaping due to leakage as fewer fish are on-station after a cage failure.

Input parameters for moderate random events (cage failures) are as follows:

- **Escapes from Cage Failure:** The probability of a cage/net pen failure in a year by size bin. Probability is applied to the total number of cages across all operations for a size bin.

The sablefish example assumes a higher probability of cage failure in pens with large fish than small fish. The assumption is pens with larger fish may require more maintenance and handling, thus the chance of pen failure is assumed to be higher. Also, the time of removal of fish for harvest may be another opportunity for cage failure due to operator error.

## Severe Random Events—Escapes due to Catastrophic Failure

Severe events are the failure of all or a majority of pens and can result in hundreds of thousands or millions of escaped fish. McKinnel and Thomson (1997) describe the loss of 7 of 10 net pens (~100,000 fish) at a farm near Cypress Island, Washington, as a result of high tidal flows. Soto et al. (2001) describe escapes of several million fish during storms in 1994 and 1995 in southern Chile. The sablefish example assumes the probability of a catastrophic loss and magnitude of the loss is highest early in the simulation period. The probability and magnitude is much less in later periods to account for assumed improvement in structures and techniques. In addition, simulation runs with a high frequency and magnitude of loss early provided some interesting insights on how large numbers of escapes have a long-term effect on a long-lived species like sablefish.

The OMEGA simulation first determines if a severe event occurred in the year. This event is assumed to occur only once a year so escapees will be those on-station at the time of the event. In other words, not all size bins may have fish during a severe failure. In fact, in a case of one production unit per year (i.e., fish transferred to the pens once a year) then fish escaping due to a severe failure will be of a single size. Multiple production groups means that fish of different sizes will be on-station at the same time and fish escaping will be of multiple sizes in a failure. The OMEGA escape simulation randomly selects a size bin for each operation and production unit in the year, of which the magnitude of loss is applied to fish of that size category.

Input parameters for severe random events (catastrophic events) are as follows:

- **Escapes from Catastrophic Events:** The probability and magnitude of a severe or catastrophic event by period defined previously for the fish culture program. The magnitude is a percent of all fish at any given time (i.e., number of fish in a size category) of an event by period.

## Gamete Release—Escapes due to Spawning in Pens

The potential "escape" of gametes and larvae from spawning of cultured fish in pens is managed by either harvesting fish before they mature or by moving maturing fish to land-based operations for brood stock spawning.

Descriptions of input parameters are as follows:

- **Release Gametes (eggs and larvae) from Pens:** Four inputs describe the potential for release of gametes:
  - size bin (kg) at which fish may mature in net pens,
  - percent of fish biomass that are female,
  - percent of female biomass that is mature and releasing eggs from the net pens, and
  - number of eggs per kg of female biomass.

OMEGA computes the number of gametes "escaping" from the net pens from the following:

$$Eggs = Biomass_{\geq MinSize} * \%Biomass_{Female} * \%Mature_{FemaleBiomass} * \frac{Eggs}{Female Kg}$$

where  $Biomass_{\geq MinSize}$  is the quantity of fish in the pens that are greater than or equal to the minimum size category that may include mature females.

The sablefish example assumes fish mature at a size larger than the largest fish in pens. Thus, the sablefish example does not include escapes due to spawning in pens. However the "escape" of eggs and larvae has been a topic of concern for Atlantic cod (Jørstad et al. 2008) and is included to account for this source of escapes.



# Interactions Component

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The Interactions component includes modules to input assumptions of survival of escapees, wild population encounter rates of escapees, spawning interactions of escapees and fitness model assumptions.

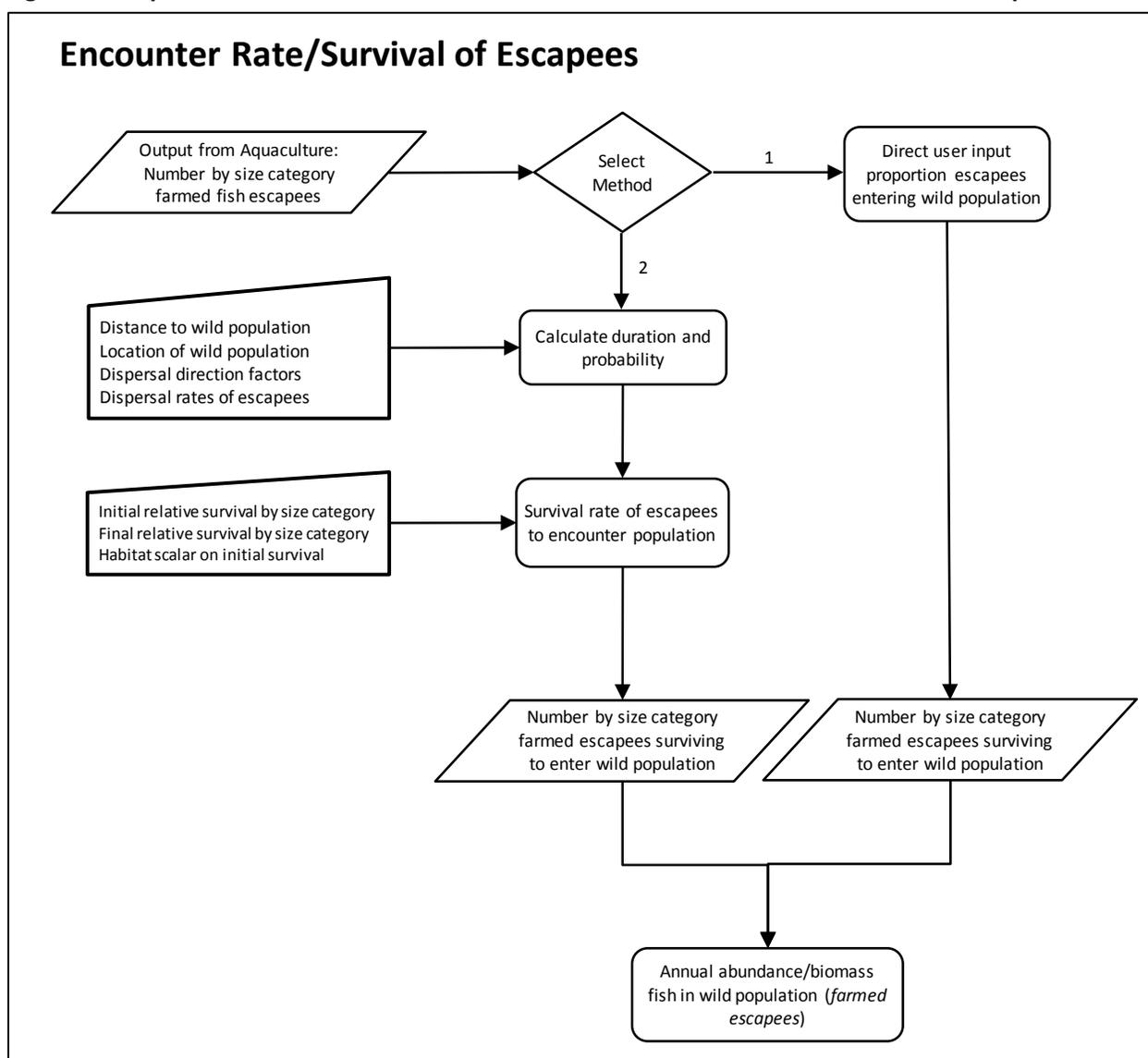
The Interactions component includes two modules to describe how escapees would interact with a wild population (Figure 6):

- assumptions of relative survival of escapees, and
- assumptions of wild population encounter rates of surviving escapees.

These modules are separate to more clearly describe factors influencing the number of escapees entering the wild population. Survival of escapees may be low, but the likelihood of escapees encountering the wild population may be high because of location of the pen operations relative to the population or dispersal rates of escapees. Conversely, survival of escapees may be high because of fish size, but their chance of encountering the wild population may be low because of location of the pen operations relative to the population.

Survival of escapees may be affected by culture practices, the level of domestication of the cultured stock, size of escapees, and environmental conditions encountered by escapees. Wild population encounter rates may be affected by distance to wild populations, currents, or behavior of escapees.

The likelihood of escaped sablefish encountering the West Coast population is unknown but likely high because of assumed location of operations and sablefish distribution along the continental shelf. Sablefish spawn in water deeper than 300 meters (Mason et al. 1983) and depending on location of the continental slope; this may be many miles offshore well away from potential marine aquaculture operations or only several miles offshore and thus much closer to where operations may be located. More importantly, juvenile sablefish move into coastal areas during their first summer and remain for 1 to 2 years before moving into deeper water as subadults and eventually along the continental slope as adults (Mason et al. 1983; Beamish and McFarlane 1988; Maloney and Sigler 2008). It seems likely that sablefish culture operations would be located within or immediately adjacent to coastal juvenile and subadult habitat.

**Figure 6. Simplified Schematic of OMEGA Process for Encounter Rates and Survival of Escapees**

Also included is a module to characterize the spawning and genetic interactions of escapees and their wild counterparts. This module includes places to input assumptions of relative breeding success of escapees and fitness parameters specific to the phenotypic fitness model developed by Ford (2002).

## Relative Survival of Escapees

This module describes the survival of escapees. Survival of escapees is likely influenced by size of escapee and survival may vary from an initial survival to survival after multiple years. Environmental conditions at the pens may also influence survival of escapees. Also included is a place to input assumptions of survival of gametes released from fish spawning in pens. In all cases inputs are survival relative to wild counterparts (size and life stage). A value of 1.0 denotes survival equivalent to wild fish and a 0.0 relative survival denotes no survival of escapees.

There is a large body of evidence showing that the post-release survival of cultured Pacific salmon is typically less than wild fish, despite culture and release strategies intended to optimize survival (Berejikian and Ford 2004; Araki et al. 2008). Less information is known for post-release survival of marine species. The few studies available focus on marine stock enhancement (see Yamashita and Yamada 1999 for a review of enhancement studies of Japanese flounder [*Paralichthys olivaceus*]). The few that report post-release survival typically are estimates of contribution rates to fisheries or are short term survival studies. None of these studies report survival of wild fish to estimate relative survival of released fish. Svåsand (2004) reviewed factors affecting post-release survival and noted the potential effect of coloration, morphology, feeding behavior, and antipredator behavior on survival of juveniles. Escapees may differ in nearly all these factors, which suggest that escapees may not survive well in nature in relation to the wild fish. Size of fish when they escape is likely an important factor. Yamashita et al. (1994) evaluated experimental releases of Japanese flounder ranging in size from 40 millimeters (mm) to 140 mm and found that survival to the fishery was highest for fish released at 100 mm. The authors concluded the difference in survival with size was because of better predator avoidance by large fish. From these studies we may conclude that survival of large escapees would be more similar to wild fish of a similar size. However large escapees may never “learn” such that their relative survival remains low throughout their life cycle.

Survival of small escapees may be more dependent on encountering suitable habitat conditions immediately after escape. Yamashita and Yamada (1999) summarized studies showing that fish size was important when considering release location of Japanese flounder. Flounder released at a small size survived well in sandy coastal areas, whereas the critical release size was larger for flounder released in coastal areas with a rocky-sandy bottom. Small escapees may survive poorly initially, but those fish remaining may survive at rates similar to wild fish after several years in the population.

Descriptions of input parameters are as follows:

- **Relative Survival of Smallest Escapee:** Survival relative to a wild fish of similar size for the smallest fish in the pen operation. Initial relative survival is survival in the first year of escape and final is after multiple years.
- **Relative Survival of Largest Escapee:** Survival relative to a wild fish of similar size for the largest fish in the pen operation. Age specific survival of wild fish is converted to size (length) specific survival to compute an equivalent survival of escapees. Initial relative survival is survival in the first year of escape and final is after multiple years.
- **Time between Initial and Final:** The number of years to reach the final relative survival.
- **Shaping Parameters:** Slope and inflection parameters to shape the relative survival logistic function.
- **Relative Survival of Gametes:** Additional survival factor applied to gametes originating from pens.
- **Environmental Factor:** Adjustment factor applied to the initial relative survival parameters. This was included to provide a simple means to explore the effect of pen location on survival of escapees and subsequent encounter with wild populations.

The sablefish example includes an effect of size of fish at escape and assumes that relative survival increases with time after escape (Figure 7). The initial and final values chosen for size classes were arbitrary, but the difference between sizes seemed reasonable. We concluded that larger escapees may have a higher initial relative survival, but their survival after several years in nature would not equal fish that escaped at a smaller size. This conclusion is in part based on an assumption that high initial mortality of small escapees would

winnnow-out the less fit fish. Those remaining would be more similar to their wild counterparts. Figure 7 shows the inputs used to determine relative survival of escapees, gametes released from fish spawning in pens, and environmental factor to account for pen location on survival.

**Figure 7. Inputs Used to Determine Survival of Escapees, Gametes, and Environmental Factor**

	Relative surv of escapees	
	Initial	Final
<b>Relative survival of smallest escapee:</b>	0.20	0.90
<b>Relative survival of largest escapee:</b>	0.40	0.60
<b>Time between initial and final (yrs):</b>	0	4
<b>Shaping parameters:</b>		
<b>Slope:</b>	6.0	
<b>Inflection:</b>	2	yrs
<b>Relative survival of gametes:</b>	0.50	
<b>Environmental factor affecting survival:</b>	1.00	

We did not include an effect of location on escapee survival. Potential sablefish pen operations are likely in open water and coastal areas or, in other words, areas where wild juvenile and sub-adult sablefish are likely to occur, suggesting no effect of environment on survival.

## Encounter Rates

Two methods are provided in OMEGA to model wild population encounter rates of escapees (Figure 6). The first method is simply a single input for encounter rate. Escapees enter the wild population at the rate specified and the rate is applied to all size classes of escapees. This method also ignores assumptions of relative survival of escapees described in the previous section. Survival of escapees in the wild population is estimated using survival assumptions for wild fish of similar size.

The second method is to include information about the seasonal distribution of the wild population with respect to the pen location, "target" size of the wild population, distance to the wild population, location of the wild population with respect to environmental influences on dispersal direction, environmental influences on dispersal direction of escapees, and dispersal rates of escapees by size class. The encounter rate is estimated by size class as the average across seasons.

We found very little information on encounter rates of marine aquaculture species to help inform the sablefish example. All of the work has been with dispersal of cultured Atlantic salmon in the Northeast Atlantic (e.g., Hansen and Jacobsen 2003), the Northwest Atlantic (e.g., Whoriskey et al. 2006), North Pacific (e.g., McKinnell and Thomson 1997) and the coastal waters of Chile (Soto et al. 2001). Whoriskey et al. (2006) reported the rapid dispersal of tagged Atlantic salmon released from aquaculture sites (most fish had left the vicinity of the pens within a day). They found that the dominant tidal circulation was important in fish dispersal direction.

Descriptions of input parameters are as follows:

- **Encounter Rate Method:** Method 1 - Apply a simple rate to all size classes of escapes, Method 2 - estimate encounter rates by size class based on distance to wild population direction angle to wild population, attraction angle, attraction strength, wild population target size, and size class dispersal rates.
- **Method 1 Rate:** Proportion of escapees that encounter wild population - same value applied to all size categories of escapees.
- **Distance and Direction:** Distance is km from pen operation to the wild population boundary and direction is the angle in degrees to the wild population. Direction becomes more of a factor when the target size of the wild population is small, such as discrete unit of habitat critical for the survival of the wild population.
- **Attraction Angle:** Angle in degrees that environmental factors such as currents may direct escapees.
- **Attraction Strength:** Relative strength of environmental factors pushing escapees in the direction of the Attraction Angle.
- **Wild Population Spatial Distribution:** Size of the wild population "target". Spatial distribution is represented as an arc in the calculations. The high value entered for sablefish essentially places the target in any direction along a 180degree arc out from the pen location.
- **Dispersal Rate:** Rate of travel (km per week) of escapees by size class.
- **Encounter Rate:** User defined value (Method 1) or estimated encounter rate (Method 2) by size class.

The sablefish example includes assumptions we developed and tested for the more complex spatial model - Method 2 (Figure 8). However, for simplicity the model demonstration is based on the simple approach (Method 1) and used an encounter rate of 1.0. The analysis assumed all escapees encountered the wild population.

Juvenile and adult sablefish are distributed along the West Coast and offshore aquaculture operations would occur within waters inhabited by the species. Escapees would likely immediately encounter juvenile sablefish and need only migrate to the continental slope to encounter mature adults.

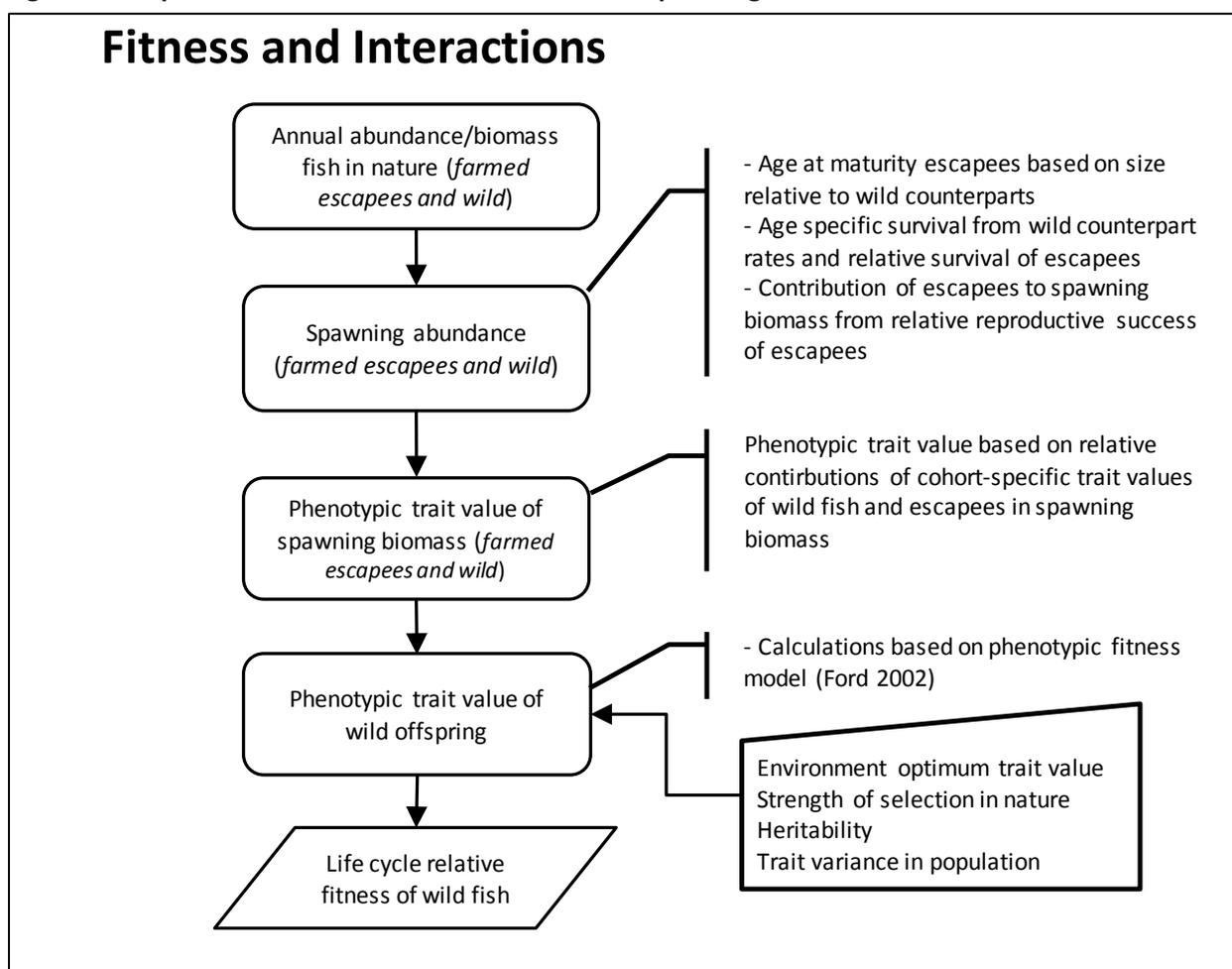
**Figure 8. Inputs used to Estimate Wild Population Encounter Rates**

<b>Encounter Rate</b>	<b>Encounter Rate Method:</b>		1
	<b>Method 1 rate:</b>		1.00
	<b>Method 2 Parameters:</b>		
		<b>Distance (km)</b>	<b>Direction</b>
	<b>Winter:</b>	500	90 °
	<b>Spring:</b>	200	90 °
	<b>Summer:</b>	200	90 °
	<b>Fall:</b>	200	90 °
	<b>Attraction Angle:</b>		90 °
	<b>Attraction Strength:</b>		Strong
	<b>Natural pop. spatial distribution:</b>		500 km
		<b>Dispersal rate (km/wk)</b>	<b>Encounter rate (estimated)</b>
	<b>Fish size class</b>		
	<b>Bin 1 - 0.015 kg</b>	2.0	1.00
	<b>Bin 2 - 0.2 kg</b>	10.0	1.00
<b>Bin 3 - 0.4 kg</b>	20.0	1.00	
<b>Bin 4 - 0.6 kg</b>	30.0	1.00	
<b>Bin 5 - 0.8 kg</b>	30.0	1.00	
<b>Bin 6 - 1 kg</b>	30.0	1.00	

## Fitness and Interactions

This module addresses spawning interactions of escapees in terms of relative reproductive success and the genetic interactions of escapees with the wild population (Figure 9).

Relative reproductive success (RRS) describes the reproductive fitness of escapees, i.e., their fitness as it relates to spawning success. RRS generally is a value between 0 (reproductively sterile escapees) to 1.0 (same spawning contribution as wild fish). It is possible that escapees may have a RRS that exceeds 1.0 if evidence supports a higher contribution to the next generation per individual compared to wild fish. RRS can be both a function of environmental effects (i.e., non-genetic factors such as culture methods or sterilization of farmed fish) and genetic factors (domestication). Much of the information on RRS is based on studies of hatchery salmonids (Berejikian and Ford 2004; Araki et al. 2008) and these studies do not make a clear distinction between non-genetic and genetic factors other than to show that hatchery fish with a long history of captive breeding (i.e., domestication) tend to have a lower reproductive fitness than hatchery fish sourced from wild fish. Meager et al. (2010) reported differences in reproductive behavior of Atlantic cod showing that farm escapees exhibit behavior that indicates a reduced RRS for this species.

**Figure 9. Simplified Schematic of OMEGA Process for Spawning and Genetic Interactions**

Included in this module are parameter inputs for the phenotypic fitness model in OMEGA. The equations are those described by Ford (2002) and described in additional detail by Campton (2009) for evaluating relative fitness effects of hatchery salmonids interbreeding with wild populations.

## Relative Reproductive Success

Reproductive success of escapees is likely affected by domestication (genetic) history and culture experience (nongenetic). Domestication may affect spawning success by such factors as spawn timing, spawning behavior, loss of secondary sexual traits, or reduced gamete production. Alternatively culture experience may be more important and would be related to the temporary effects of culture experience on ability locate spawning fish, size of escapees relative to wild fish, and possibly spawning behavior. It is possible that if the effects are entirely non-genetic that over multiple breeding events escapees may more competent and RRS would increase.

Two options are provided to incorporate reproductive success in the analysis. The first is a computation of reproductive success of escapees based on the phenotypic trait model and predicted value for cultured fish. Reproductive success may initially be low if the cultured fish have a low initial relative fitness (sourced from a

domesticated brood source) or may start high and decline rapidly as the cultured stock becomes domesticated.

The second option is to ignore computed relative fitness of the cultured population and assume an initial and long-term relative reproductive success of escapees. OMEGA includes options to shape the transition from initial to long-term success.

Descriptions of input parameters are as follows:

- **Include Genetic Effect (Y/N):** Yes (Y) – compute relative reproductive success based on computed phenotypic trait value of escapees; No (No) – use input assumptions for relative reproductive success
- **Minimum Relative Reproductive Success:** Initial reproductive success of escapees.
- **Maximum Relative Reproductive Success:** Long-term reproductive success of escapees.
- **Slope/Inflection:** Shaping parameters: Slope and inflection parameters to shape the logistic function.

The sablefish example includes parameters that shape RRS from an initial low value and after several breeding cycles the RRS of escapees is equal to wild fish (Figure 10).

## Genetic and Fitness Effects

The phenotypic fitness model is a two population analysis of different environmental selection regimes acting on the two populations and the effect of gene flow between populations on mean trait value of the populations. Assumptions of the model are following:

- A single trait is under selection with different optimum values for the two environments.
- The trait is normally distributed and subject to bell-shaped (Gaussian) selection.
- All mating is random; fish do not sort by origin (escapee and wild).
- Population size is large so that random drive, phenotypic plasticity, and other stochastic forces can be ignored.
- Changes in mean trait value are deterministic based on selection and gene flow.
- Selection does not reduce population size, variance or heritability of the trait over time.

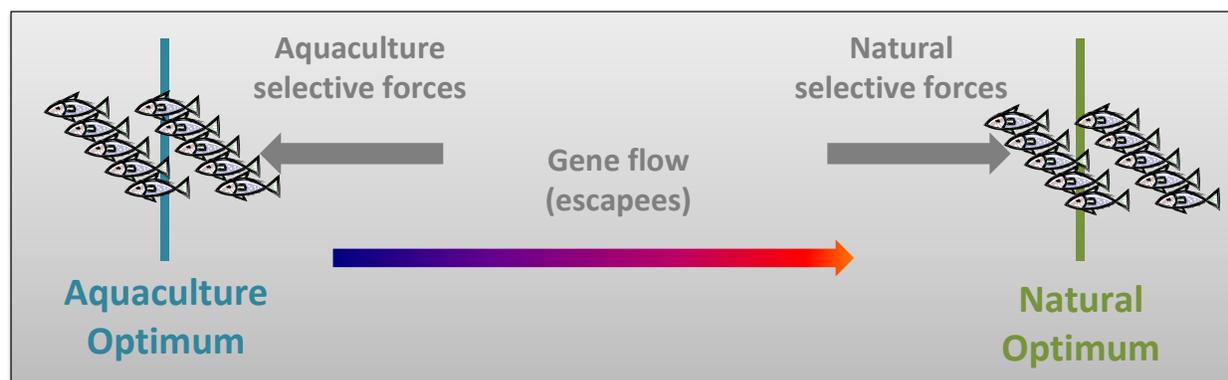
The concept of the model is described in Figures 11 and 12. The initial condition is where the mean trait value of the two populations is equal to their respective environmental optimums (Figure 10). In this example gene flow is one direction with escapees breeding with the wild population. An alternative model may include gene flow from the wild population to the cultured population as determined by the percent cultured brood stock sourced from the wild population (see previously discussed section on Brood Stock Source for a more details).

**Figure 10. Inputs to Describe Reproductive and Genetic Interactions for Sablefish**

<b>Genetic Fitness and Interactions</b>	<b>Apply estimated fitness effects:</b>	Y		
	<b>Fixed assumed nat population fitness:</b>	0.90		
	<b>Fitness model Parameters:</b>	<b>Hatchery</b>	<b>Natural</b>	
	<b>Initial Trait Value:</b>	80	100	
	<b>Environmental optimum:</b>	80	100	
	<b>Strength of selection:</b>	5	5	
	<b>Heritability:</b>	0.50		
	<b>Trait Variance:</b>	10		
	<b>Allocation fitness effect across life cycle:</b>			
	<b>Spawning:</b>	0.50		
	<b>Juvenile Survival (Egg to Subadult):</b>	0.40		
	<b>Adult Survival (Post-Subadult):</b>	0.10		
	<b>Relative Breeding Success of Escapees:</b>			
	<b>Include genetic Effect:</b>	N		
	<b>Parameters for Non-genetic component:</b>			
	<b>First time spawning:</b>	0.80		
	<b>Maximum:</b>	1.00		
	<b>Non-genetic shaping parameters:</b>			
	<b>Slope:</b>	2.00		
	<b>Inflection:</b>	4 yrs		
<b>Competitive interaction factor:</b>	1.00			

The resulting condition is a change in the mean trait value of the wild population (Figure 11). Figure 11 provides a simplified overview of the single trait fitness model with initial condition of two populations, two environmental optimums and mean trait values of populations same as respective environmental optimums.

**Figure 11. Simplified Overview of Single Trait Fitness Model**



The deviation of the wild population from the optimum phenotypic value is  $\bar{P}_{Wild} - \theta_{Nat}$ .

The mean phenotypic trait values of wild and cultured progeny in year  $y$  are calculated by the following equations (Ford 2002):

$$\begin{aligned} \bar{P}_{Wild,y} = & (1 - pHOS_{sp}) \left[ \bar{P}_{Wild,sp} + \left( \left( \left( \bar{P}_{Wild,sp} \omega_{Nat}^2 + \theta_{Nat} \sigma^2 \right) / \left( \omega_{Nat}^2 + \sigma^2 \right) \right) - \bar{P}_{Wild,sp} \right) h^2 \right] \\ & + pHOS_{sp} \left[ \bar{P}_{Escapee,sp} + \left( \left( \left( \bar{P}_{Escapee,sp} \omega_{Nat}^2 + \theta_{Nat} \sigma^2 \right) / \left( \omega_{Nat}^2 + \sigma^2 \right) \right) - \bar{P}_{Escapee,sp} \right) h^2 \right] \end{aligned}$$

and

$$\begin{aligned} \bar{P}_{Culture,y} = & (1 - pNOB_{brood}) \left[ \bar{P}_{Culture,brood} + \left( \left( \left( \bar{P}_{Culture,brood} \omega_{Culture}^2 + \theta_{Culture} \sigma^2 \right) / \left( \omega_{Culture}^2 + \sigma^2 \right) \right) - \bar{P}_{Culture,brood} \right) h^2 \right] \\ & + pNOB_{brood} \left[ \bar{P}_{Wild,brood} + \left( \left( \left( \bar{P}_{Wild,brood} \omega_{Culture}^2 + \theta_{Culture} \sigma^2 \right) / \left( \omega_{Culture}^2 + \sigma^2 \right) \right) - \bar{P}_{Wild,brood} \right) h^2 \right] \end{aligned}$$

where:

$pHOS_{sp}$  = Proportion of spawning biomass in nature that is escapees

$pNOB_{brood}$  = Proportion of aquaculture brood stock that is wild fish

$\theta_{Nat}$  = Phenotypic optimum or expected value (mean) of the phenotypic probability distribution for the natural environment

$\theta_{Culture}$  = Phenotypic optimum or expected value (mean) of the phenotypic probability distribution for the culture environment

$\sigma^2$  = Phenotypic variance for the trait in question

$h^2$  = Phenotypic trait heritability

$\omega_{Nat}^2$  = Variance of the probability distribution of fitness as a function of phenotypic values for individuals in the natural environment

$\omega_{Culture}^2$  = Variance of the probability distribution of fitness as a function of phenotypic values for individuals in the culture environment

$\bar{P}_{Wild,sp}$  = Mean phenotypic value of the wild population spawning in year  $y$

$\bar{P}_{Escapee,sp}$  = Mean phenotypic value of cultured adults (escapees) spawning in year  $y$

$\bar{P}_{Wild,brood}$  = Mean phenotypic value of the wild brood stock in year  $y$

$\bar{P}_{Culture,brood}$  = Mean phenotypic value of the cultured brood stock in year  $y$

Because OMEGA is an annual simulation model and the trait model is a generational analysis we need to compute an average trait value for the wild population that accounts for fish contributing to spawning from multiple brood years each with a potentially different trait value. In the above equations,  $\bar{P}_{Wild,sp}$  and  $\bar{P}_{Escapee,sp}$  are calculated as the mean phenotypic value of the escapee and wild adults spawning in year  $y$  comprised of age classes ( $a$ ):

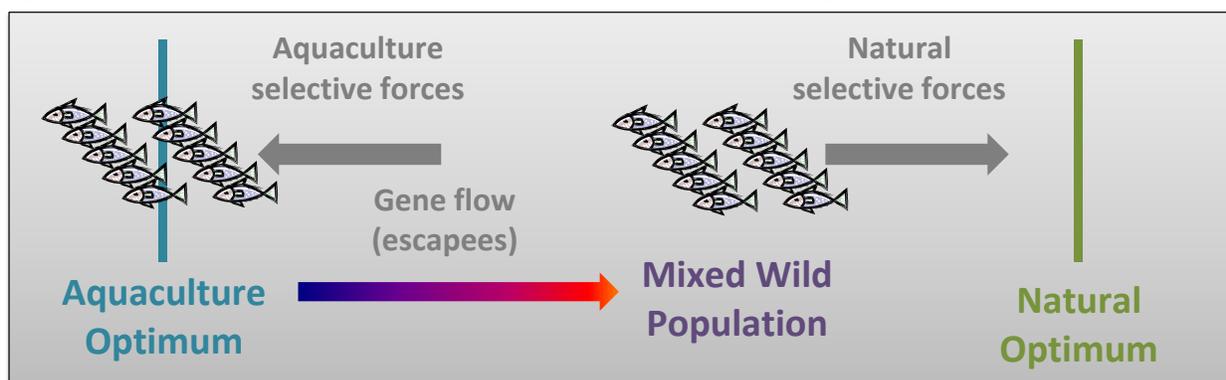
$$\bar{P}_{Wild,sp} = \frac{\sum_{a=i}^A N_{Wild,a} \bar{P}_{Wild,a}}{\sum_{a=i}^A N_{Wild,a}}$$

and

$$\bar{P}_{Escapee,sp} = \frac{\sum_{a=i}^A N_{Escapee,a} \bar{P}_{Escapee,a}}{\sum_{a=i}^A N_{Escapee,a}}$$

These equations assume that cohort contribution to recruitment was proportional to abundance in the spawning biomass. This approach is a simplification as it overlooks the potential of unequal recruitment rates among cohorts due to differences in age specific female fecundity and, more importantly, fitness. Figure 12 provides a representation of the resulting case with gene flow to the wild population and a change in the wild population mean trait value.

**Figure 12. Gene flow to Wild Population and Mean Trait Value Change**



A similar issue arises when computing annual trait value for the culture brood stock. In previous equation the trait value of wild adults in the brood stock ( $\bar{P}_{Wild,brood}$ ) is assumed to be the same as wild spawners ( $\bar{P}_{Wild,sp}$ ). Culture fish in the brood stock also includes multiple cohorts with potentially different trait values. OMEGA was modified to include inputs to describe the age composition of culture adults in the brood stock and the mean annual trait value of the culture brood stock is calculated by the following:

$$\bar{P}_{Culture,brood} = \sum_{a=i}^A f_{Culture,a} \bar{P}_{Culture,a}$$

Where  $f_{Culture,a}$  is the user input fraction of the hatchery brood stock of age  $a$ .

Finally, the mean relative fitness ( $RF$ ) of the wild fish cohort, offspring from spawning in year  $y$ , is calculated by the following:

$$RF_{Cohort,y} = e^{\frac{-(\bar{P}_{Wild,sp} - \theta_{Nat})^2}{2(\omega_{Nat}^2 + \sigma^2)}}$$

The effect of relative fitness on cohort survival is likely a function of the trait in question and the effect may be during spawning, juvenile phase (prior to the fish entering harvest) or across multiple years up to and beyond first spawning. Allocation of fitness effect across the life cycle is included as parameter values in OMEGA. Relative fitness is allocated across the life cycle by the following:

$$f_i = RF^{RelLoss_i}$$

Where  $f$  is the relative fitness effect in life phase  $i$  and  $RelLoss_i$  is assumed proportion of the total life cycle relative fitness effect in life phase  $i$ .

The extent of interbreeding between escapees and their wild counterparts is a function of parameters describing the size of the aquaculture operations, the percent of escapees, the relative survival of escapees and the chance escapees will encounter the wild population to interbreed. These parameters are specific to a particular aquaculture scenario to be analyzed and can be based, to some extent, on empirical observations or experience. The phenotypic trait model relies on assumptions for a set of parameters (environmental optimum, trait heritability, trait variance, and trait selection) that likely will not come from direct empirical data. This uncertainty suggests an evaluation with a range of parameter values to explore effects and sensitivity to assumptions specific to the fitness model.

Descriptions of input parameters are as follows:

- Initial Trait Value:** The initial phenotypic trait value for the aquaculture and wild population  $\bar{P}_{Culture,Initial}$  and  $\bar{P}_{Wild,Initial}$ . Wild population is nearly always 100 and the aquaculture trait value something less if originating with a cultured brood stock or 100 if originating with wild fish.
- Environmental Optimum:** Phenotypic optimum for the natural and culture environments  $\theta_{Nat}$  and  $\theta_{Culture}$ . Natural environment is always 100 and the aquaculture optimum something less to represent differential selection pressure.
- Strength of Selection:** The strength of selection for the two environments is expressed as  $\omega_{Nat}^2 = \omega_{Nat} \sigma^2$  and  $\omega_{Culture}^2 = \omega_{Culture} \sigma^2$  where  $\omega$  is the input parameter value in OMEGA.  $\omega_{Nat}^2$  and  $\omega_{Culture}^2$  are variance of the fitness function for the two environments.
- Heritability:** This is trait heritability  $h^2$  in the equations. Campton (2009) referenced two sets of heritabilities  $h^2 = 0.2$  (moderate heritability) and  $h^2 = 0.5$  (strong heritability). Trait heritability is assumed to the same for the two populations. The sablefish example is based on strong heritability.
- Trait Variance:** This is trait variance  $\sigma^2$  in the equations. Trait variance is assumed to be the same for the two populations.

Parameters used in the sablefish example are described in Figure 10.



# Wild Population Production Component

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The third component of OMEGA is the characterization of the wild population productivity, survival and harvest (Figure 13). The wild population simulation in OEMGA is an age-structured single population model with age-specific assumptions for survival, harvest, and maturity. The life cycle process is separated into four phases: 1) spawning biomass, 2) egg production, 3) juvenile recruitment, and 4) subadult/adult survival. Harvest is included during the subadult and adult phase and is shaped by an age-specific double logistic function. We developed the population model in OMEGA based on many of the concepts and processes of the Stock Synthesis population assessment model for marine fish management (Methot 2000). However, OMEGA is a much simpler construct of the population model in Stock Synthesis.

This component includes three modules:

- Natural production with wild population recruitment and age specific survival,
- Growth and maturity of the wild population, and
- Age-specific harvest selectivity and maximum annual exploitation rate.

The model simulation is initialized with a user input initial biomass. However, to remove any initial parameter effects on results the simulation includes a 20 step/year initialization period with survival and harvest assumptions, but absent survival variation and escapes. This is done to reach an equilibrium population size prior to analysis of effects of escapees on population abundance. The consequence is the input initial spawning biomass may differ from results in year 1 of the simulation. In the sablefish example we set the wild population parameter values, then ran the model with an approximate initial spawning biomass, and then revised the initial spawning biomass to match biomass in year 1 of the simulation.

Analytical components of the population model in OMEGA are as follows:

Female spawning biomass (*SPB*) of wild fish is as follows:

$$SPB_{Wild} = \sum_{a=1}^A (N_{f,y,a} * M_a * W_{f,a})$$

Where  $N_{f,y,a}$  is the number of wild females of age  $a$  in the population in year  $y$ ,  $M_a$  is the fraction of females mature at age  $a$ , and  $W_{f,a}$  is the body weight of females at age  $a$ . The number of females of a particular age assumes a 50:50 sex ratio in the population.

Female spawning biomass (*SPB*) of escapee fish is as follows:

$$SPB_{Escapees} = \sum_{a=1}^A (N_{f,y,a} * M_a * W_{f,a} * RelReprod_a)$$

Where  $N_{f,y,a}$  is the number of escapee females of age  $a$  in the population in year  $y$ ,  $M_a$  is the fraction of females mature at age  $a$ ,  $W_{f,a}$  is the body weight of females at age  $a$  and  $RelReprod$  is the relative reproductive success of escapees at age  $a$ .

Egg production is calculated by the following:

$$Eggs = (SpawnBiomass_{Escapee} + SpawnBiomass_{Wild}) * \frac{Eggs}{Kg} * f_{spawn}$$

Egg to end of juvenile recruit period is based on two parameter Beverton-Holt survival function (assumption of density-independent productivity and maximum number recruits or capacity). Setting the capacity very high will ignore the effect of population abundance on survival during this phase. The Beverton-Holt function is as follows:

$$\text{Recruits} = (P * \text{Eggs}) / (1 + \frac{P * \text{Eggs}}{C})$$

where  $P$  is the density-independent productivity and  $C$  is capacity each adjusted for life phase relative fitness ( $f_{\text{Recruit}}$ ).

The number of subadult and adult fish surviving to the next year is calculated by the following:

$$N_{y+1} = N_y e^{-Z}$$

where  $Z$  is the age specific instantaneous rate mortality and includes natural (adjusted for relative fitness) and fishery mortality.

Age-specific natural mortality is described with a logistic function shaping survival. Fishery selectivity is based on a logistic function with an option to include a descending component (double logistic function) for older ages.

## Natural Production

This module has standard inputs for a population model-initial spawning biomass and eggs per kg of female body weight. It includes parameter inputs for the Beverton-Holt survival function and an input to define the ages of the Beverton-Holt recruitment phase. Age specific survival for subadults and adults is defined by parameters for the logistic function (slope and inflection age). Also defined in this module is the maximum age to use in the population model.

Descriptions of input parameters are as follows:

- **Female Spawning Biomass:** Includes initial female spawning biomass, eggs per kg of female body weight, and a coefficient of variation to include random variation in egg production.
- **Beverton-Holt Stock-Recruit Parameters:** Defines age for the end of the recruitment phase, capacity of maximum number of individuals at the end of the phase, and a coefficient of variation to include random variation in recruitment. The productivity parameter is taken from the next set of inputs.
- **Natural Mortality:** Defines maximum age in the population and initial and maximum survival of individuals.
- **Logistic Shaping Function:** Slope and inflection age to shape the survival logistic function.

A simplified schematic of the OMEGA process for modeling natural production and harvest parameters is shown in Figure 13. Parameters used in the sablefish example are described in Figure 14. These parameters were taken from Schirripa (2007) to the extent possible.

## Growth and Maturity

This module includes the basic von Bertalanffy growth parameters for males and females, in terms of length (cm) and a length (cm) – weight (kg) conversion for males and females. Also included is a section to describe

age at maturity of females. Maturity schedule is based on fish length and convert to age based on the length-weight and growth functions.

Descriptions of input parameters are as follows:

- **von Bertalanffy Growth Parameters:** The maximum and initial size of fish and the von Bertalanffy growth constant ( $k$ ). Age is years.

$$L = L_{Max} + (L_{Initial} - L_{Max})e^{-ka}$$

- **Length (cm) to Weight (kg) Conversion:** Alpha and beta parameters for the length to weight conversion power function:

$$W = aL^b$$

- **Female Maturity Schedule:** Logistic function to shape maturity. Age of youngest spawner forces the maturity to 0 at that age. Female length at 50% mature is the logistic function inflection point. Beta is slope of the function.

A simplified schematic of the OMEGA process for modeling natural production and harvest parameters is shown in Figure 13. Figure 14 contains parameters used in the sablefish example including inputs to describe population age structure, larvae to subadult recruitment, adult mortality rates, growth and female maturity schedule of wild sablefish.

## Harvest

This module describes selectivity logistic function and maximum harvest rate ( $F_{max}$ ). OMEGA models fishery mortality as a single value. Selectivity of alternative gear type as reported for sablefish (Schirripa (2007) was not included in OMEGA.

Descriptions of input parameters are as follows:

- **Include Descending Function in Selectivity (Y/N):** No (N) – exclude a descending function in selectivity. Yes (Y) – include a descending portion for older fish that may avoid fishery because of size or distribution.
- **Age at Recruitment:** Initial age entering fishery and age at terminal or full recruitment to fishery. Descending portion parameters define age to begin descending selectivity and terminal reduced selectivity.
- **Logistic Shaping Function:** Slog and age of inflection for selectivity functions.

Figure 15 provides inputs to describe age specific fishery selectivity and maximum exploitation rate for sablefish.

**Figure 13. Simplified schematic of OMEGA Process for Modeling Natural Production and Harvest**

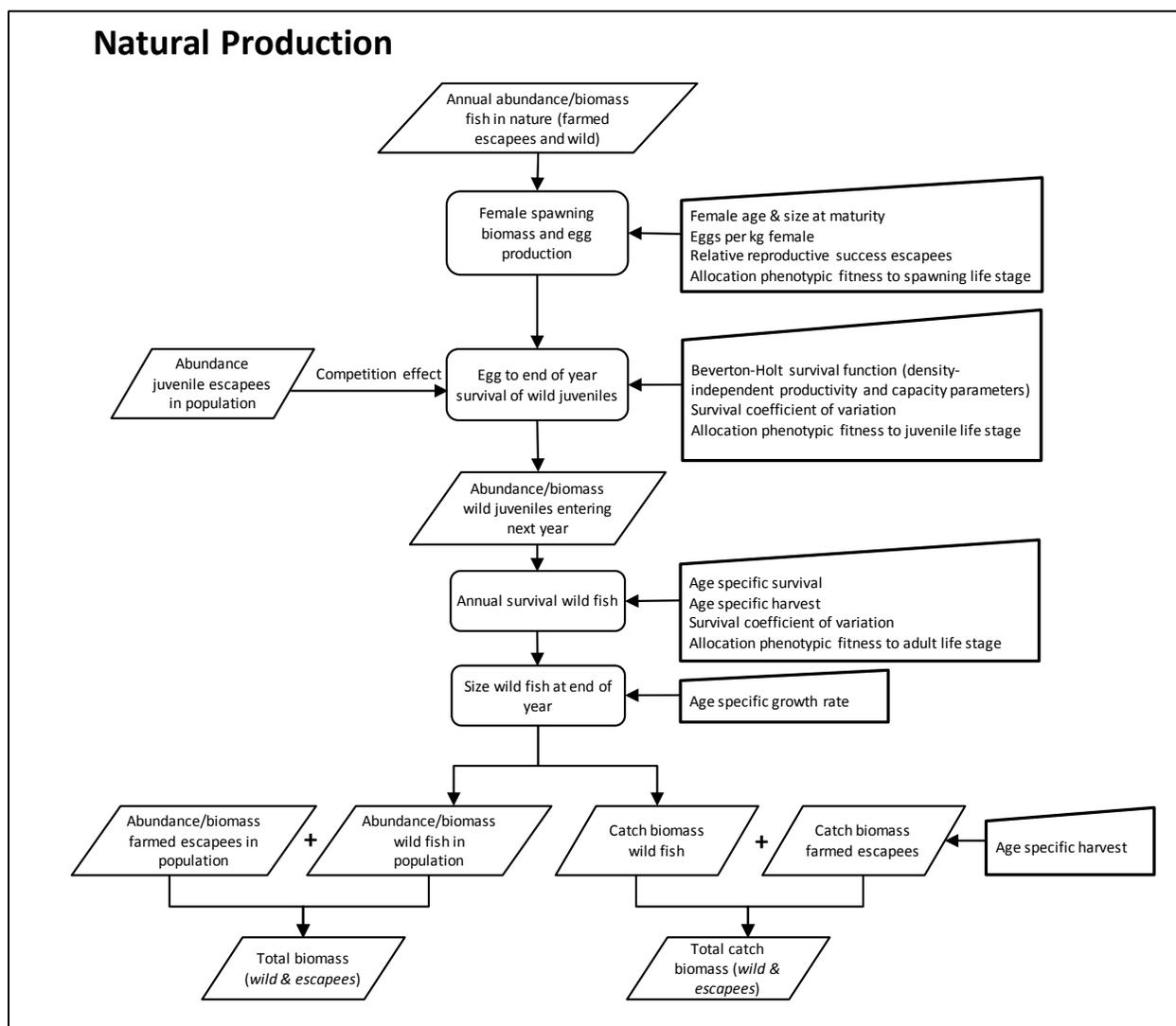


Figure 14. Inputs for Sablefish Natural Production and Growth Parameters

<b>Natural Production</b>	<b>Initial Female spawning biomass:</b>	90,000	mt
	<b># Eggs per kg female:</b>	55,000	
	<b>Breeding success C.V.:</b>	0.25	
	<b><u>Beverton-Holt stock-recruitment parameters:</u></b>		
	<b>Age end recruitment:</b>	2	yr
	<b>Capacity (# of fish):</b>	20,000,000	
	<b>Recruitment survival C.V.:</b>	0.05	
	<b><u>Natural mortality parameters:</u></b>		
	<b>Maximum age:</b>	65	
	<b>Mean surv egg to end first year:</b>	0.00002	
	<b>Mean survival maximum:</b>	0.93	
	<b>Survival C.V.:</b>	0	
	<b>Apply Semelparous breeding (Y/N):</b>	N	
	<b><u>Natural mortality logistic shaping parameters:</u></b>		
<b>Slope:</b>	1.5		
<b>Inflection:</b>	1	yr	
<b>Growth and Female Maturity - Natural Production</b>	<b><u>von Bertalanffy Growth in nature</u></b>	<b>Females</b>	<b>Males</b>
	<b>Length cm (max):</b>	66.2	55.8
	<b>Length cm (initial):</b>	38.44	38.44
	<b>k (growth const):</b>	0.25	0.30
	<b><u>Length (cm) to wt (kg) conversion:</u></b>	<b>Females</b>	<b>Males</b>
	<b>alpha:</b>	2.4419E-06	2.4419E-06
	<b>beta:</b>	3.347	3.347
	<b><u>Female maturity schedule:</u></b>		
	<b>Age youngest spawner:</b>	3	
	<b>Female length (cm) at 50% mature:</b>	55.3	
	<b>beta:</b>	0.249	
	<b><u>Calculated age specific maturity:</u></b>		
	<b>Age</b>	<b>% mature</b>	
	1	0.00	
2	0.00		
3	0.09		
4	0.24		
5	0.42		
6	0.58		
7	0.70		
8	0.78		
9	0.83		
10	0.86		

**Figure 15. Inputs for Age-Specific Fishery Selectivity and Maximum Exploitation Rate for Sablefish**

<b>Harvest</b>	<b>Ascending &amp; descending selectivity:</b>	No	
	<b>Ascending selectivity only:</b>	Yes	
	<b><u>Ascending selectivity parameters:</u></b>	<b>Age</b>	<b>Selectivity</b>
	<b>Initial recruitment:</b>	4	0.10
	<b>Maximum recruitment:</b>	20	1.00
	<b><u>Ascending selectivity shaping parameters:</u></b>		
	<b>Slope:</b>	0.40	
	<b>Inflection (age):</b>	5	
	<b><u>Descending selectivity parameters:</u></b>	<b>Age</b>	<b>Selectivity</b>
	<b>Terminal recruitment:</b>	45	0.80
	<b><u>Descending selectivity shaping parameters:</u></b>		
	<b>Slope:</b>	0.50	
	<b>Inflection (age):</b>	40	
	<b>Max fishing mortality (full selectivity):</b>	0.03	

# OMEGA Model Demonstration

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The following example illustrates the application of OMEGA to evaluate the impact of farmed escapees on wild populations. This example uses a hypothetical commercial aquaculture operation for sablefish (*Anoplopoma fimbria*) along the coast of Washington, Oregon and California. The scenario datasets were developed to test and demonstration the model characteristics, sensitivity to assumptions and capabilities. This example is to show how escapes can affect a population abundance and long-term viability and how limiting escapes can greatly reduce impacts to fitness and abundance of the wild population.

The example scenarios are not intended to describe the operations of an actual sablefish aquaculture industry, or standards that should be used to regulate operations. They are provided only to describe the functions of the model.

As mentioned previously, the sablefish example is particularly interesting because the wild population is large, sablefish are intensively managed by the Pacific Fishery Management Council and as such information on life history and population dynamics is readily available (Schirripa 2007), the culture of sablefish has long been of interest (Kennedy 1972), and just recently culture methods have been developed to allow the spawning and cultivation of sablefish to harvestable size (M. Rust personal communication). Concerns have been raised over the environmental, ecological, and genetic implications of sablefish culture (Robichaud et al. 2004; Sumaila et al. 2005). The high value of sablefish in the commercial fishery and the development of culture methods have promoted an increasing interest in the commercial culture of sablefish in Canada.

In nature, sablefish reach maturity at 6 years of age and can live up to 80 years. Fish are fully selected to the fishery at 4 to 5 years of age. In culture, sablefish can grow to a harvestable size of 1 kg in approximately 52 weeks. In this example, the culture program is assumed to consist of 50 separate offshore pen operations, each containing multiple pens with different size classifications as fish grow to harvestable size. Total culture production is assumed to be 10,000 mt per year.

For the two scenarios described below, natural production, harvest, culture production, encounter rates, and fitness and interactions including genetic effects are the same. The only difference between the scenarios is escape rates. Escapes from a culture program can occur due to many factors, which are categorized as severe random events (also called catastrophic events in OMEGA), moderate random events (e.g., cage failures), and chronic losses (e.g., base leak rate, or fish that escape due to factors other than cage failures, including unknown causes). The scenarios differ in all three sources of escapes.

Finally, the distributed OMEGA model (Version 1.0) includes the two scenarios described in this section. The following results are based on 10 model iterations to demonstrate effects of escape randomization and variability in wild population survival.

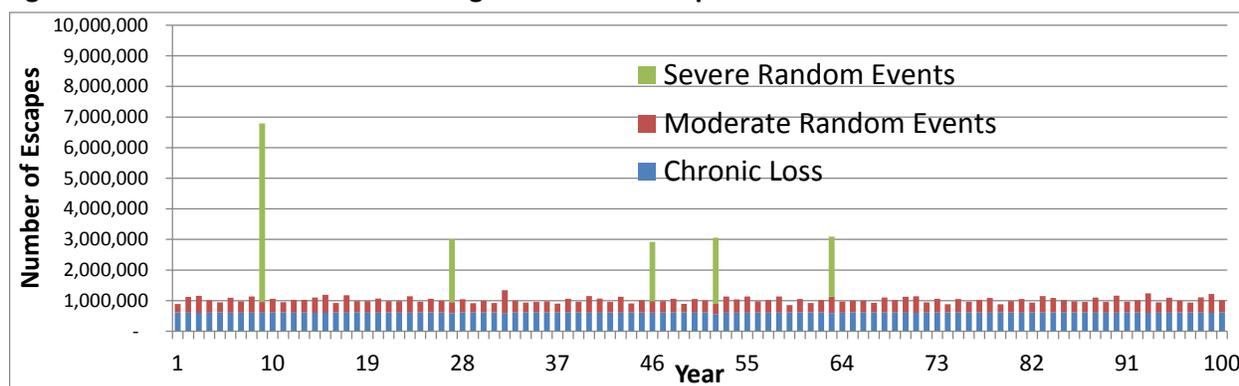
## Sablefish Scenario 1: High Escape from Culture Operations

Escape parameters used in Scenario 1 illustrate a hypothetical program that is vulnerable to high rates of escape. The parameters used in the scenario are not intended to describe operating conditions for an existing or planned facility, nor are they intended to inform regulatory standards. The narrative in this section is intended to describe the model response under an escape scenario that includes a relatively high leakage and

high probability of catastrophic events. When viewed in the context of recent escape data from salmon programs in British Columbia, escape levels applied in this scenario are high and do not represent a fully mature. .

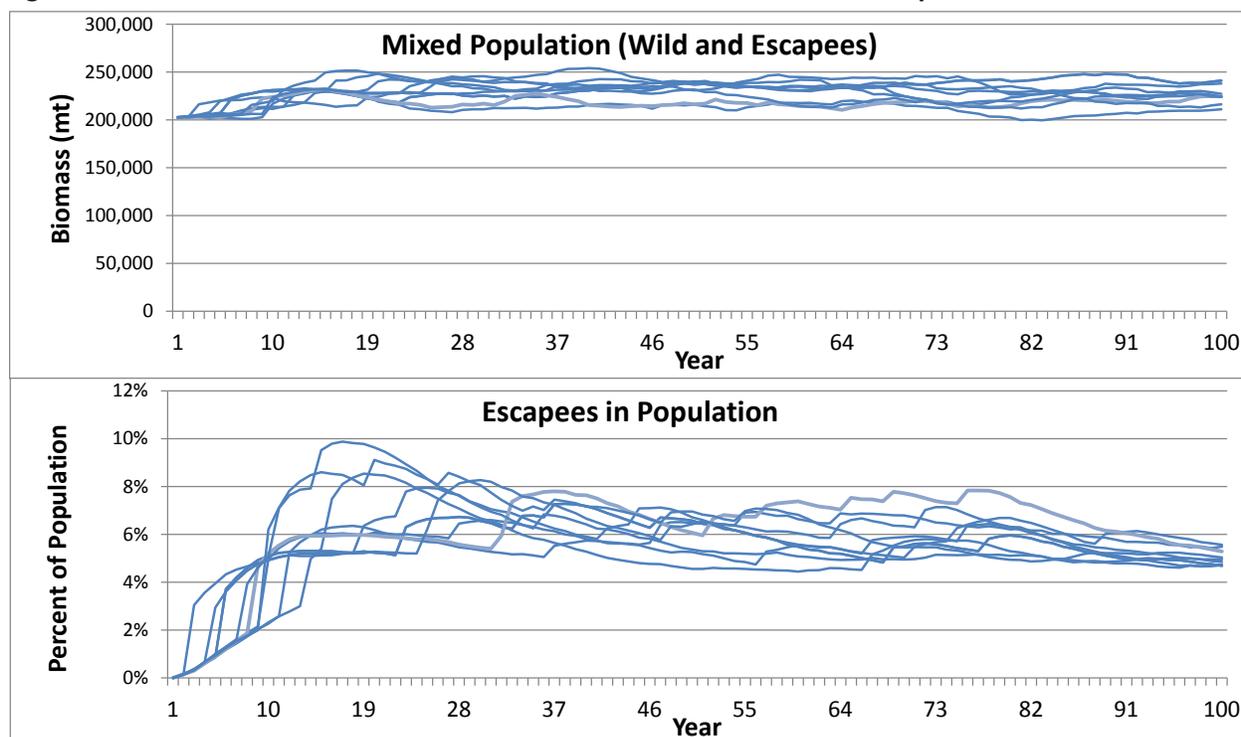
In Scenario 1 starting in year 1, catastrophic events are assumed to occur with a probability of 10% on a given year and each event results in a 60% loss of cultured stock. In year 16 of the program, it is assumed technology improvements result in a reduced probability of catastrophic events and the chance of a severe event is reduced to 5% and fewer fish escape (40%). Beginning in year 26 severe events are assumed to be less severe (20% of fish escape) but with the same 5% probability of occurrence. The scenario assumes that chronic losses are highest for small fish (3% leakage) and lower for larger fish (0.5%). This level of chronic loss is assumed throughout the entire 100-year simulation period. Moderate severe events (cage failures in OMEGA) are low for pens with small fish (0.5%) and high for pens with large fish (1.0%). This too is applied across the entire 100-year simulation period. Figure 16 shows total escape numbers across all 50 operations for a single simulation. Chronic losses and moderate events together average about 1.0 million fish escaping per year. This is an extremely high percent of total production (10.0 million fish at harvest size) and would represent an extreme example of escapes due to chronic and moderate events. The simulation included five severe events, early in the simulation a large magnitude event occurred. The remaining four events were of lower magnitude. Figure 16 shows the average number of escapes due to various factors over ten 100-year simulations for Sablefish Scenario 1.

**Figure 16. Sablefish Scenario 1—Average Number of Escapes due to Various Factors**



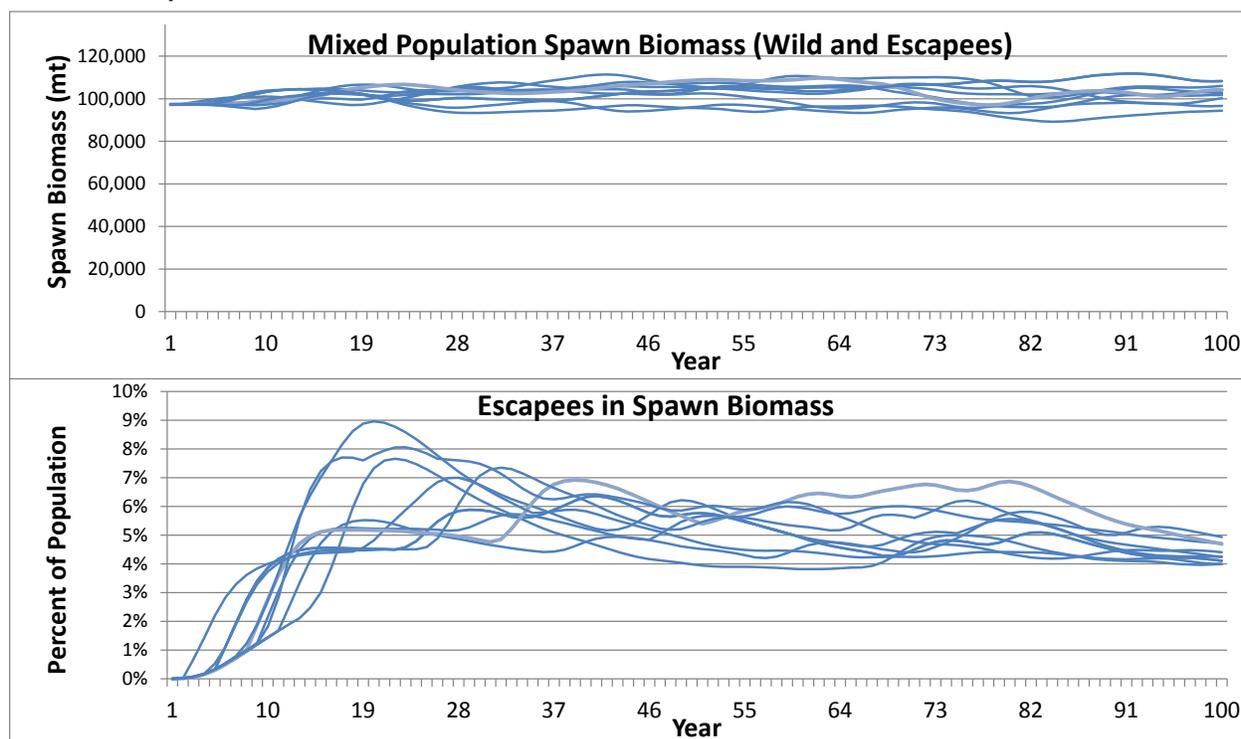
The example assumes all escapees survive to encounter the wild population. Relative reproductive success of escapees was assumed to be 0.80 for initial spawning and increased to 1.0 after fish experienced several spawning cycles.

Escapees entering the wild population resulted in a notable increase total biomass of sablefish (Figure 17). As the cultured fish escape into the wild, the composition of escaped fish in the natural population increases, reaching a level of between 5% and 8% after approximately year 25 and lasting until year 100 of the simulation. Figure 17 shows the total biomass (escapees and wild) and percent biomass of escapees over ten 100-year simulations for Sablefish Scenario 1.

**Figure 17. Sablefish Scenario 1—Total Biomass and Percent Biomass of Escapees**

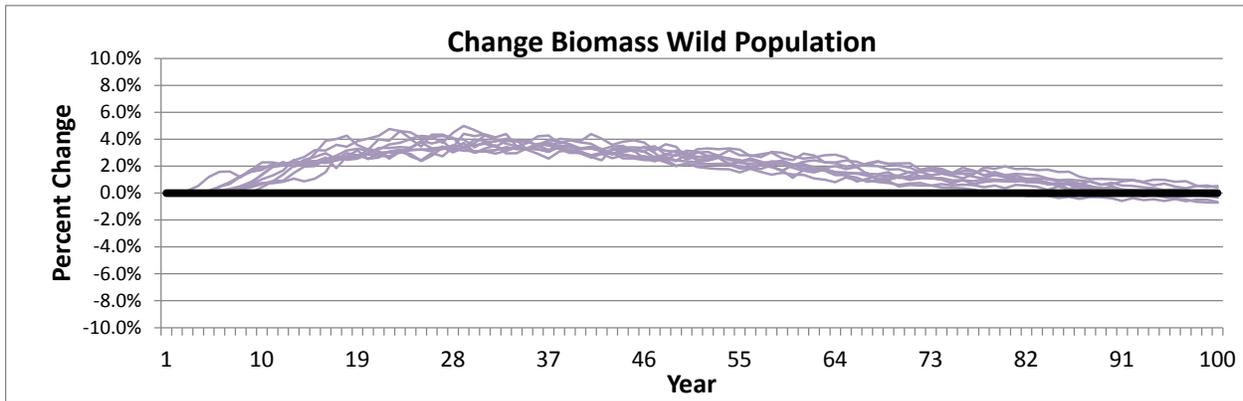
Initial female spawning biomass was just less than 100,000 mt and varied between 90,000 mt and 110,000 mt (Figure 18). The percent of escapees in the spawning biomass increased quickly with some early peaks due to severe escapee events. Escapees comprised between 4% and 7% of the spawning biomass after year 40. Figure 18 shows the total biomass of females spawning in nature (wild and escapees) and escapee spawning biomass composition over ten 100-year simulations for Sablefish Scenario 1.

**Figure 18. Sablefish Scenario 1—Total Biomass of Females Spawning in Nature and Escapee Spawning Biomass Composition**



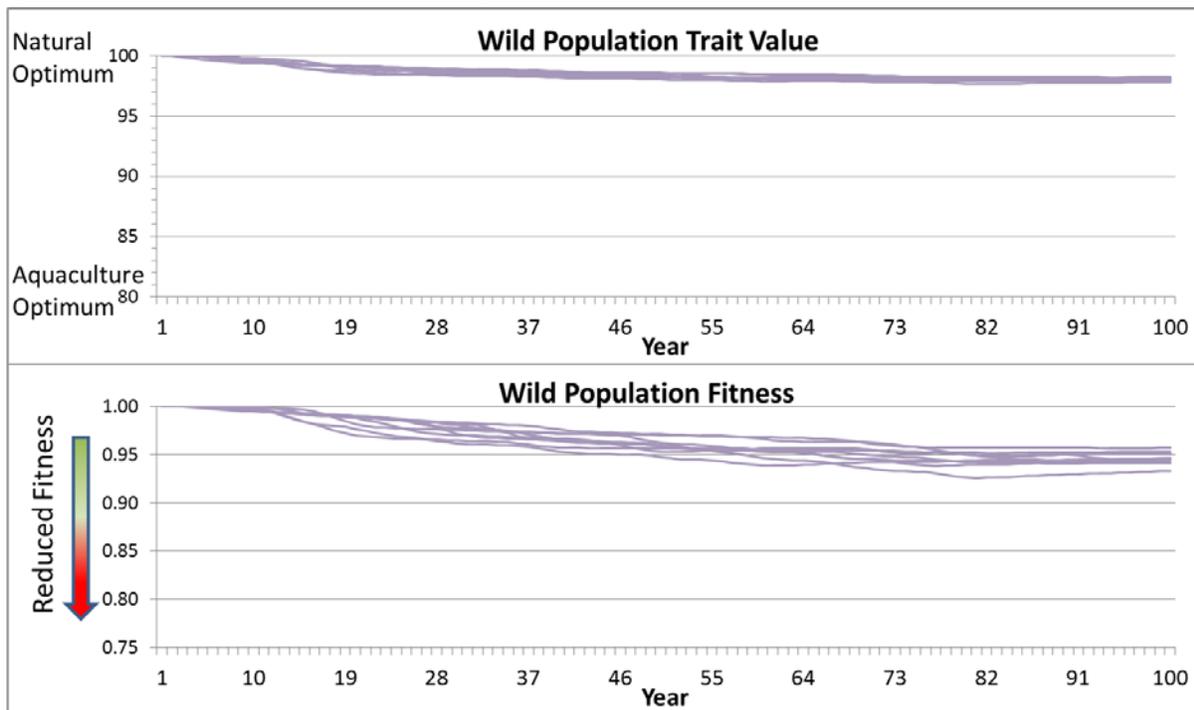
The effect of escapees on biomass of wild fish (fish born in nature) was an initial increase relative to the no-escapee reference (Figure 19). While the effect of escapees entering the population increases overall biomass as shown in Figures 17 and 18, recruitment of wild fish initially increases and then declines steadily over the 100-year period as reduced fitness affects the ability of fish to survive. However, long-term the trend in biomass was declining and by year 100 the biomass of wild fish was less than the reference condition. Two items were of interest: the pattern of wild fish biomass is increasing early in the simulation in response to escapees contributing to spawning biomass, and after approximately year 40, the trend is decreasing biomass of wild fish even though trend in total biomass (escapees and wild) and total spawn biomass (escapees and wild) does not show the same decline (Figures 17 and 18). The pattern of decline suggests the trend likely continued beyond the 100 year simulation. Figure 19 shows the natural production of the mixed population (spawning biomass includes escapees) relative to baseline (no escapees) over ten 100-year simulations for Sablefish Scenario 1.

**Figure 19. Sablefish Scenario 1—Natural Production of Mixed Population Relative to Baseline**



The response of the wild population in terms of phenotypic trait value and relative fitness is shown in Figure 20. These results represent trait value and relative fitness of offspring by year. The phenotypic trait value of the wild population is moving towards the aquaculture optimum value over the 100-year simulations. Consistent with the change in trait value, fitness responded fairly quickly to the effect of escapees on the population. It appears fitness may have reached equilibrium by year 75. The results show a lag between biomass of wild fish (Figure 19) and fitness (Figure 20). The trend is biomass was increasing as fitness was declining. This lag is due to the retention of older, larger and fit adults in the spawning biomass. As these more fit fish die out over time the population is shifting to less fit adults and the consequence is a decline in wild production. The results of Scenario 1 indicate year-over-year declining fitness and reduced survival of wild fish. The long-lived nature of sablefish is a factor in the delayed effect on wild fish biomass. Figure 20 shows the wild population mean trait value and relative fitness over ten 100-year simulations for Sablefish Scenario 1.

**Figure 20. Sablefish Scenario 1—Wild Population Mean Trait Value and Relative Fitness**



## Sablefish Scenario 2: Low Escapes from Culture Operations

Scenario 2 explores a scenario where escape rate is significantly less than in Scenario 1. This scenario represents management of the aquaculture operations to reduce the chance and magnitude of random events. As with Scenario 1, the parameters used in the scenario are not intended to describe operating conditions for an existing or planned facility, nor are they intended to inform regulatory standards. The results and narrative in this section is intended to describe the model response under an escape scenario that includes a relatively low leakage and lowhigh probability of catastrophic events.

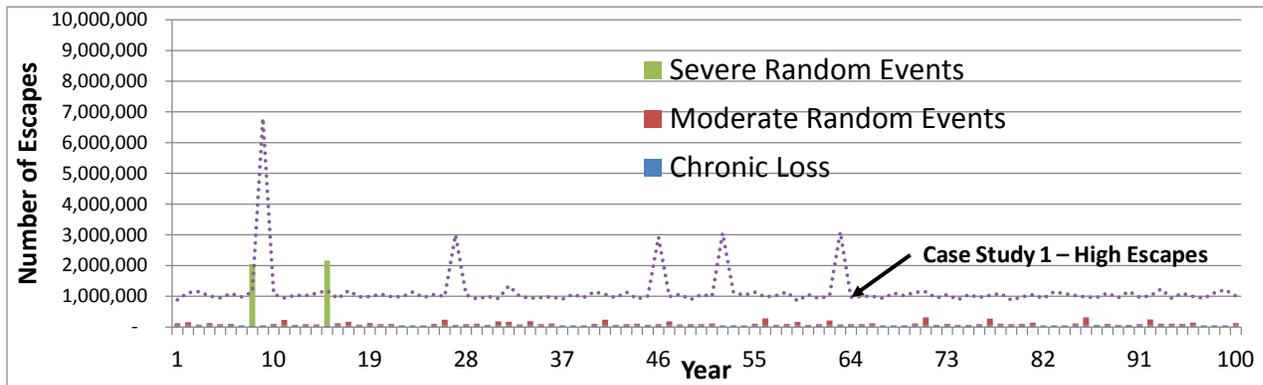
In each of the figures for this scenario the average results from Scenario 1 are included for comparison. The ability to do this comparison is a function included in OMEGA, and is central to the purpose of the model. This is a comparison between a user set reference scenario and the working scenario (e.g., in this example Case Studies 1 and 2, respectively)<sup>1</sup>. This allows the user to explore alternatives such as the sensitivity of outcomes to culture operations, effects of interactions, and effects of scale of culture operations. In this way the user can develop a customized sensitivity analysis based on a set of known parameters about a natural population, such as sablefish, and variable parameters of a culture operation. Developing an understanding of the relationships between different environmental factors may point the way toward designing programs that meet goals of environmentally sustainable aquaculture programs.

In Scenario 2 starting in year 1, catastrophic events are assumed to occur with a probability of 5% on a given year and each event results in a 20% loss of cultured stock. In year 26 of the program, it is assumed technology improvements result in a reduced probability of catastrophic events (1%) with no change in the magnitude of loss. The scenario assumes that chronic losses are the same across all fish sizes (0.1% leakage). This level of chronic loss is assumed throughout the entire 100-year simulation period. Moderate severe events (cage failures in OMEGA) are the same across all size categories (0.1%). This too is applied across the entire 100-year simulation period. Figure 21 shows total escape numbers across all 50 operations for a single simulation. Chronic losses and moderate events together average about 200,000 fish escaping per year. **MR: 2 orders of magnitude higher then salmon in BC with 100K mt/year.** Severe events occur during the first 25 years, but the magnitude of these events is low. From year 26 to 100 the severe events are rare and only occurred once for the 10 model iterations. Figure 21 shows the average number of escapes resulting from various factors over ten 100-year simulations for Sablefish Scenario 2.

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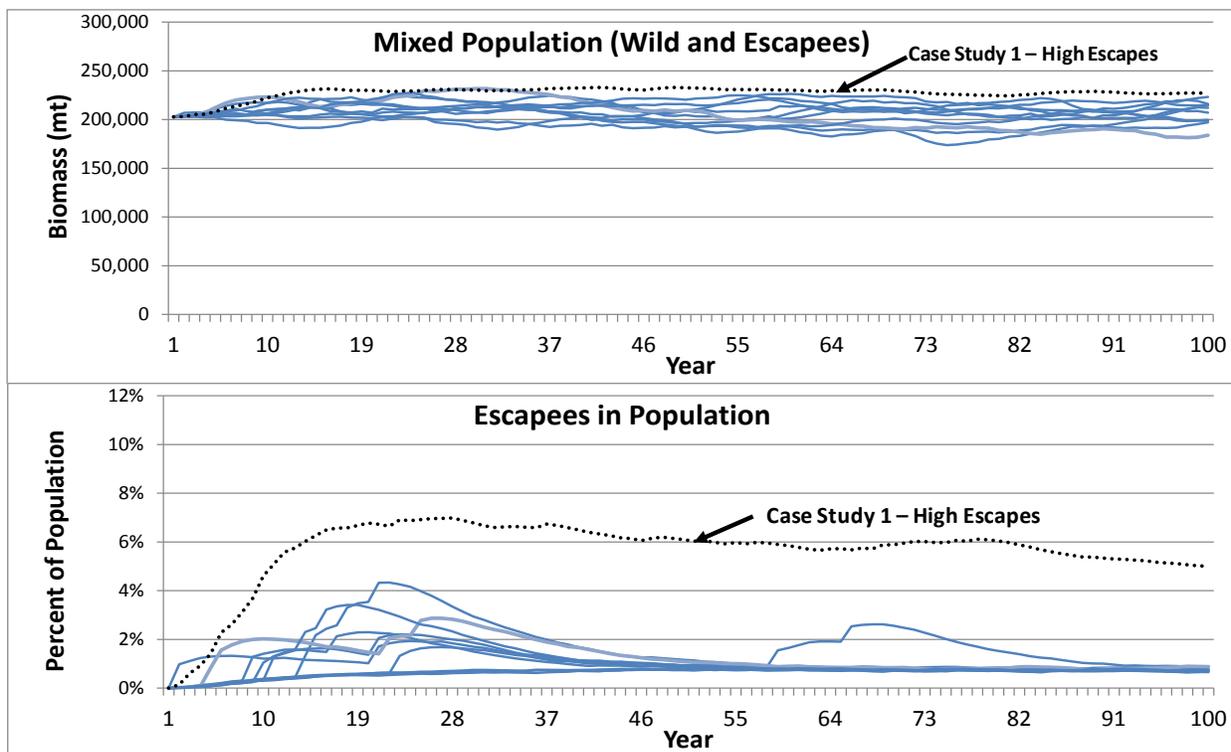
<sup>1</sup> Setting a reference scenario is described in the User Guide section of this report.

**Figure 21. Sablefish Scenario 2—Average Number of Escapees due to Various Factors**



Because of the low rate of escape under this scenario, the biomass of the natural population increases only slightly and remains at a fairly steady state over the 100-year simulation period (Figure 22). Escapees were approximately 1% of the total biomass after year 50 with the exception of one iteration that included a severe event after year 50. Figure 22 shows the total biomass (escapees and wild) and percent biomass that is escapees over ten 100-year simulations for Sablefish Scenario 2.

**Figure 22. Sablefish Scenario 2—Total Biomass and Percent Biomass**



Initial female spawning biomass was just less than 100,000 mt and varied between 80,000 mt and approximately 105,000 mt (Figure 23). The percent of escapees in the spawning biomass increased quickly with some early peaks due to severe escapee events. Escapees comprised less than 1% of the spawning biomass after year 50 with the exception the one iteration with a severe event after year 50. Figure 23 shows the total biomass of females spawning in nature (wild and escapees) and escapee spawning biomass composition over ten 100-year simulations for Sablefish Scenario 2.

**Figure 23. Sablefish Scenario 2—Total Biomass of Females Spawning in Nature**

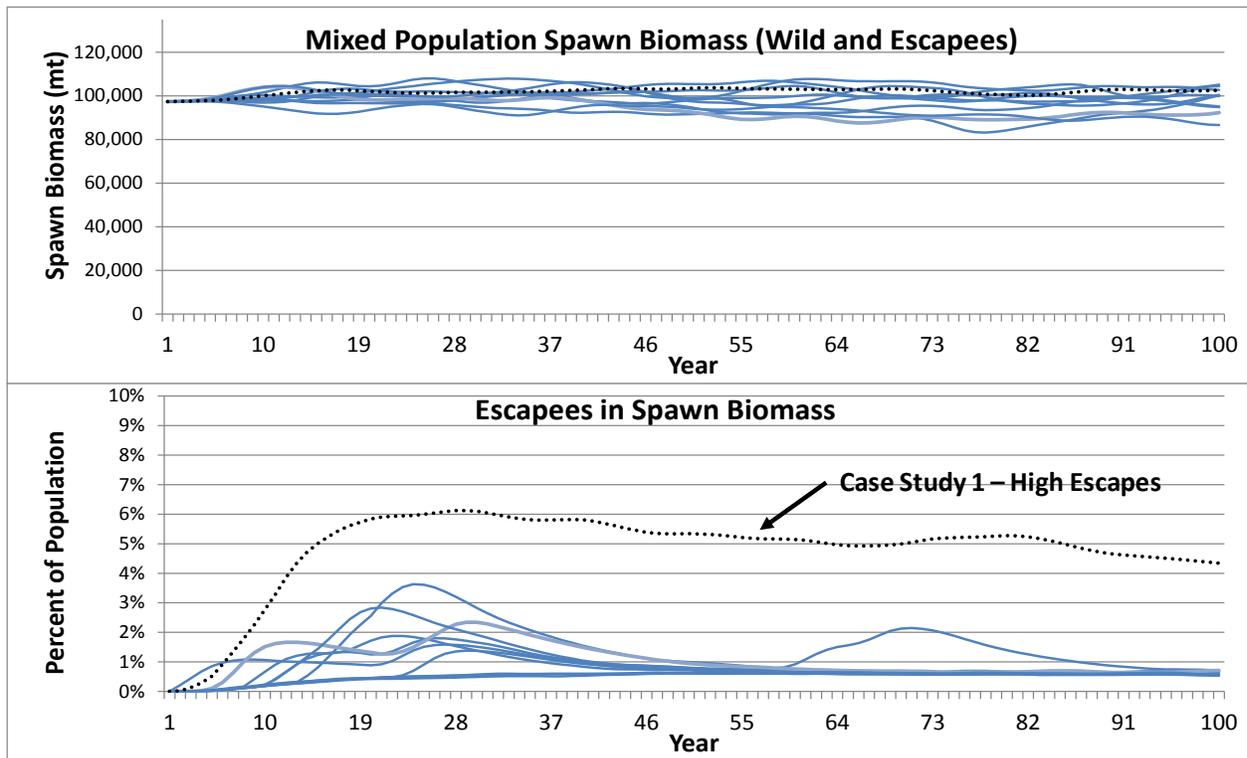
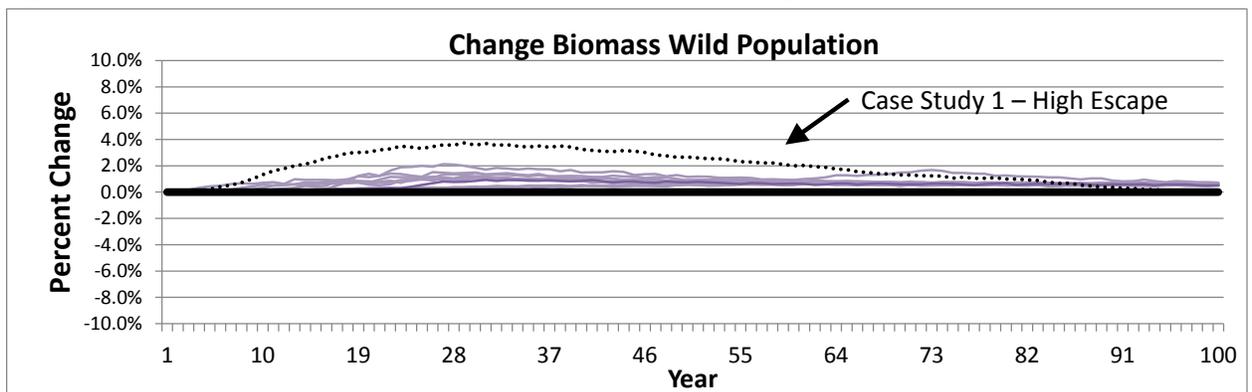


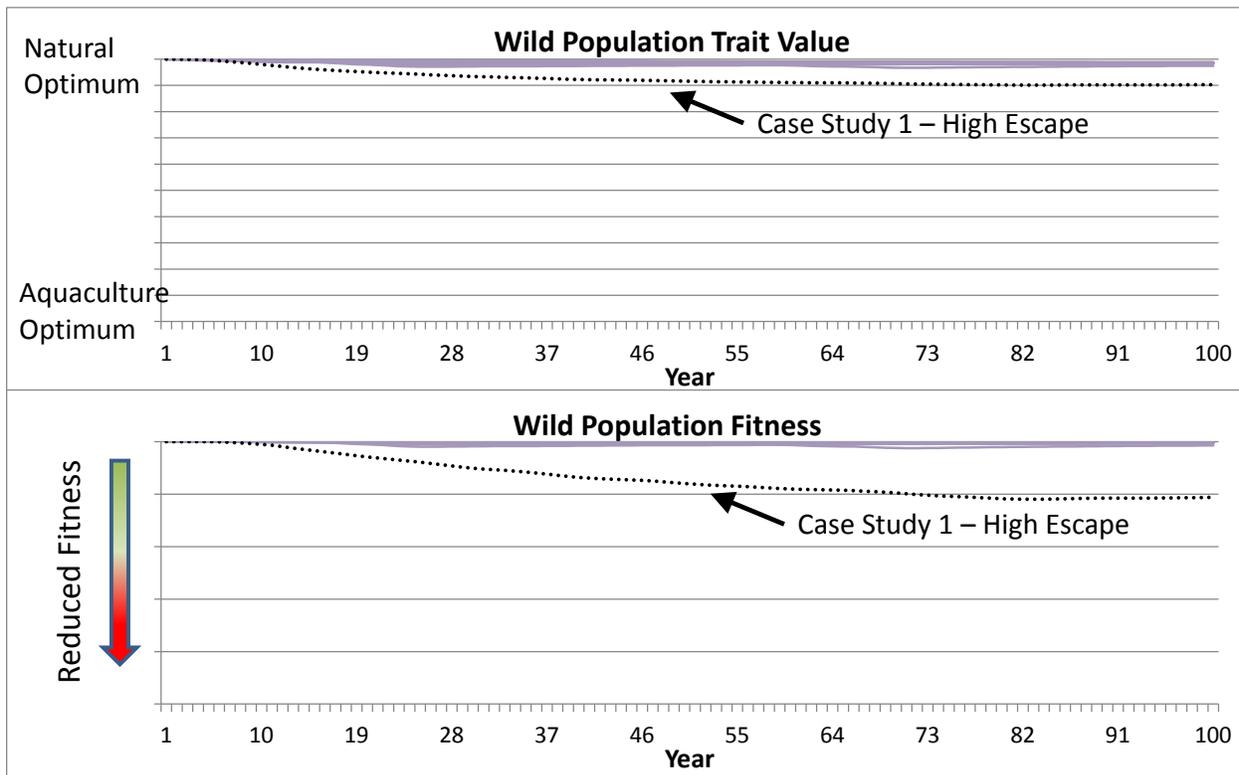
Figure 24 shows the response of the wild population in terms of biomass of wild fish in the population relative to the no-escapes reference. The results for Scenario 2 show a slight increase in wild production and this slight increase continues to year 100. The introduction of escapes at low levels provides a slight boost in spawning biomass resulting in a slight increase in wild production. Figure 24 shows the natural production of the mixed population (spawning biomass includes escapees) relative to baseline (no escapees) over ten 100-year simulations for Sablefish Scenario 2.

**Figure 24. Sablefish Scenario 2—Natural Production of Mixed Population Relative to Baseline**



The response of the wild population in terms of phenotypic trait value and relative fitness is shown in Figure 25. Even a low level of escapees resulted in a shift in the phenotypic trait value of the wild population toward the aquaculture optimum value over the 100-year simulation. Consistent with the slight shift in trait value, relative fitness also declined slightly. Figure 25 shows the wild population mean trait value and relative fitness over 100-year simulation for Sablefish Scenario 2.

**Figure 25. Sablefish Scenario 2—Wild Population Mean Trait Value and Relative Fitness**





## **Volume II. OMEGA User Guide**

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# About the User Guide

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The following is a step-by-step guide to developing a dataset for OMEGA, performing calculations, running simulations, reviewing results, and saving data. The guide is intended to provide enough detail about the model interface that a user can successfully complete an analysis. This user guide was written for OMEGA Version 1.0, the first version ready for distribution. Features present in later versions may differ slightly from what is discussed in this guide.

## OMEGA Users

OMEGA is designed to be used by scientists and policy analysts to evaluate scenarios for a single species at an aquaculture operation in areas where there are existing wild conspecific populations. Various data sources are required to create a complete dataset that accurately reflects characteristics of the aquaculture operation, natural population, and survival of escapees. OMEGA enables individuals to understand interactions and explore management options and—in a workshop setting with a group of people—evaluate possible consequences of alternative regulatory standards.

## Software Requirements

OMEGA was programmed in Microsoft Excel Visual Basic for Applications (Excel VBA). Opening and running OMEGA requires Microsoft Excel. While OMEGA operates well in any version of Excel, the application performs calculations up to three times faster under Excel 2010 compared to Excel 2007. The difference in overall calculation speed can be quite significant, depending on the speed of a computer's central processing unit (CPU).

OMEGA's user interface was designed for a monitor resolution of 1024 by 768 pixels (1024 x 768). This resolution allows ideal full-screen viewing using most overhead projectors; however, any monitor resolution will work. OMEGA also includes a quick zoom feature that can set the viewing window to the desired size. The zoom can be set in the active program window using the keystrokes Control + left-bracket (Ctrl + “[”) or Control + right-bracket (Ctrl + “]”).

## Launching OMEGA

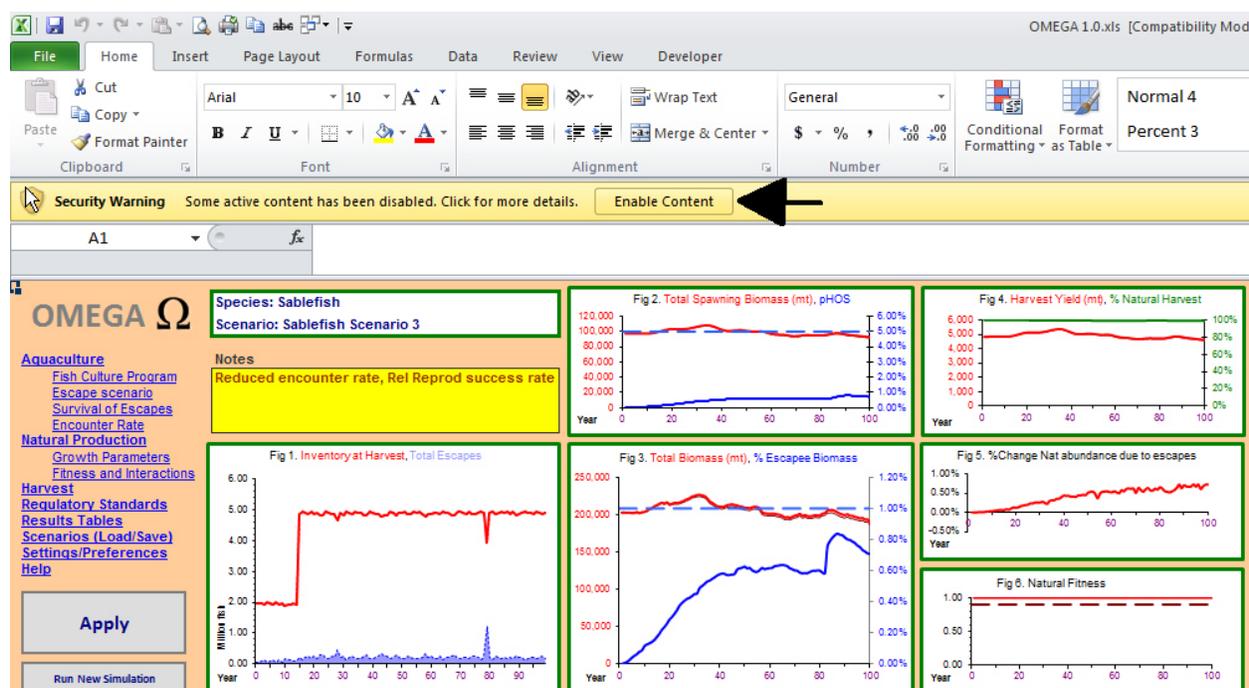
Any open Excel files should be closed prior to launching OMEGA. Other Excel workbook files can run concurrently with OMEGA, but for best performance they should be open in separate instances of the Excel application. In other words, if an Excel workbook is open and the user wants to keep it open, simply launch a second instance of the Excel program in a separate window and open OMEGA from there. This will avoid conflicts that may occur from macros running in OMEGA and other Excel workbooks.

Open the OMEGA program by double-clicking the OMEGA.xls file or by opening the file via Excel.

## Macro Security Levels in Excel

When opening OMEGA using Microsoft Windows, a security warning message will appear immediately upon opening Excel, below the Ribbon. Click *Enable Content*. If the security message does not appear it is likely your security settings are set to *Disable All Macros without Notification*. If the security message does not appear then go to File → Options → Trust Center → Trust Center Settings → Macro Settings and set Macro Settings to *Disable all Macros with Notification*. Next close OMEGA and Excel then reopen Excel and OMEGA. A message will appear that asks you to specify whether to enable macros in the file. Click *Enable Content* and then *OK* (Figure 26). OMEGA has not been tested on Apple computers.

**Figure 26. Enabling Macros in Excel 2010**



### Important Note

#### Important Note

This is the first widely distributed version of OMEGA and errors/bugs may be encountered specific to a particular Excel installation, computer hardware, or when running the model with parameter values that are not compatible with the model calculations.

Please contact us if you encounter an error or are having difficulty running the application:

- Jason Volk (programmer) ICF International, Jason.Volk@ICFI.com
- Greg Blair (fish biologist) ICF International, Greg.Blair@ICFI.com

Some errors/bugs can be corrected easily by the user. Please see the Troubleshooting section for a discussion.

### Opening OMEGA

The OMEGA application opens to a welcome page when the macros are activated (Figure 27). Click anywhere on the welcome page to begin working in OMEGA.

Figure 27. OMEGA Welcome Page

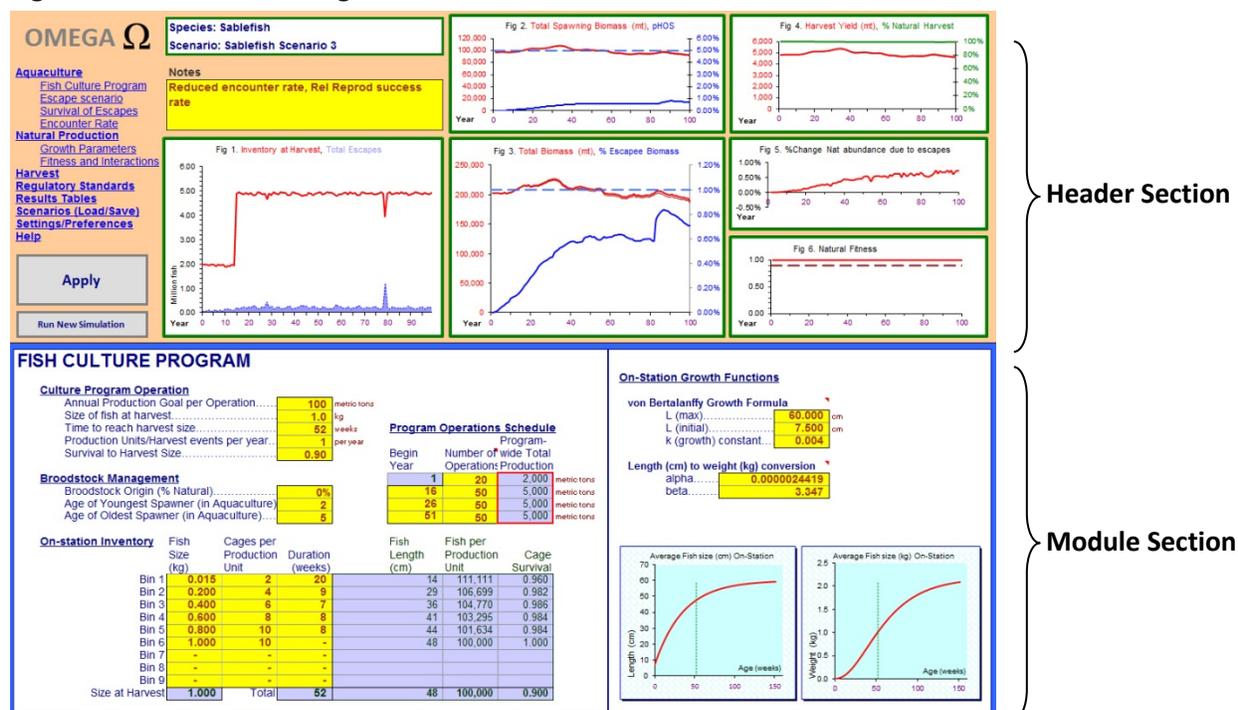


The application opens onto the main page shown in Figure 28. All OMEGA interface functions, including input parameters and charts are located on the main page.

The OMEGA model is organized around modules that correspond to defined categories of data. For instance, the Fish Culture Program Module contains input parameters specific to aquaculture operations such as number of fish cultured to harvest, number and size of fish reared in the pens, brood stock source, and total assumed production across all operations. More detail on modules and how to use them is discussed later in the Using OMEGA section.

One of the most useful aspects of OMEGA is the ability to view changes in population response by varying culture operations and model parameters, and saving them as scenarios. Working in this fashion, the user can observe the sensitivity of population responses to certain combinations of parameters, and visualize whether changes made to the working analysis result in a population response that moves closer to achieving a desired outcome.

Figure 28. OMEGA Main Page



There are two sections on the main page:

- **Header Section:** The Header Section contains the OMEGA Navigation Bar, information about the particular simulation (species, scenario, and notes), and result charts summarizing important outputs from a model simulation.

The Navigation Bar is located on the left side just below the OMEGA symbol. Just below the Navigation Bar are two options for running a model simulation. The choice of clicking *Apply* or *Run New Simulation* depends on whether the user desires to run the model with fixed randomization (*Apply*) or run the model with new randomization (*Run New Simulation*). The difference between these options is explained in more detail in the Running Calculations in Omega section later in this guide.

The header section is fixed and always appears in the top half of the main page. Thus, all navigation functions and results are accessible at any time, regardless of the current module being used.

- **Module Section:** The module section contains the user input parameters. The set of parameters shown in this section depends on the module selected by the user from the Navigation Bar. The module can be changed by clicking on an item in the Navigation Bar, or by simply dragging the Excel view scrollbar up or down to the desired module. Clicking on items in the Navigation Bar is a quick way to show the desired module neatly in the current window.

## Application Map

Before users begin to use OMEGA a basic familiarity of the modules and functions is helpful. As described previously, the main page contains all available OMEGA functions. The main page has several different possible views, which are summarized in the application map on Figure 29. The views are changed by clicking on a module in the Navigation Bar in the header section. The order of moving through the modules to set up the input parameters is up to the user.

Additional functions are contained on the main page to explore possible regulatory guidance values, manage species and scenario datasets, view tabular results, view and configure settings/preferences, and view help items (Figure 30).

Figure 29. OMEGA Modules Application Map

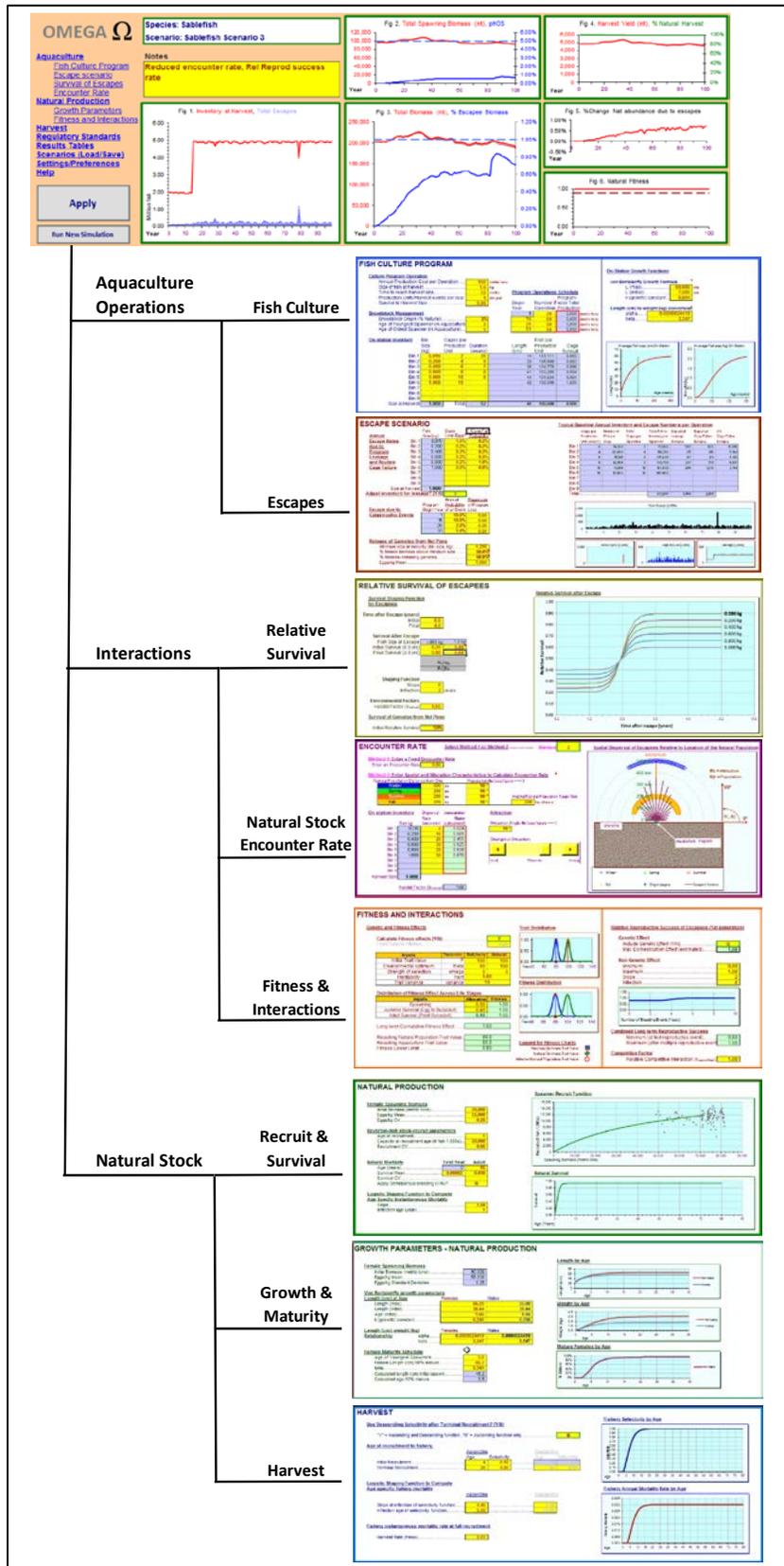


Figure 30. OMEGA Main Page

**OMEGA** Ω

**Aquaculture**

- [Fish Culture Program](#)
- [Escape scenario](#)
- [Survival of Escapes](#)
- [Encounter Rate](#)

**Natural Production**

- [Growth Parameters](#)
- [Fitness and Interactions](#)

**Harvest**

- [Regulatory Standards](#)
- [Results Tables](#)
- [Scenarios \(Load/Save\)](#)
- [Settings/Preferences](#)
- [Help](#)

Apply

Run New Simulation

**Species: Sablefish**

**Scenario: Sablefish Scenario 3**

**Notes**

Reduced encounter rate, Rel Reprod success rate

### Regulatory Standards/Guidance

**REGULATORY STANDARDS (provided for demonstration purpose)**

**Aquaculture Program Regulatory Standards**

pHOS Upper Limit: 5.00% ← Expressed as a percentage escapée spawners of total spawning biomass

Escapement Limit: 1.00% ← Expressed as a percentage of escapes in the total biomass of conspecific

Natural Fitness Lower Limit: 0.7000

**Analysis**

The aquaculture program is projected to conform to escape percent of total spawning and total biomass limits, and allowable levels of natural fitness. This program is projected to be in compliance.

### Tabular Results

**RESULTS TABLES**

	Average	Max	Min
<b>Working Scenario 1 Establish, Scenario J1</b>			
Biomass (kg)	206,109,767	206,887,852	89,034,616
Yield (kg)	4,317,967	5,373,738	4,617,363
Total Spawn Biomass (kg)	99,097,707	106,301,600	82,453,087
Escapée Spawning Biomass (kg)	430,468	709,374	0
Total Escapes (number)	203,439	329,383	49,631
% Escapée spawners @ % Escapées	11.64%	11.89%	11.00%
Natural Fitness	0.9997	1.0000	0.9993
<b>Heterocene Scenario</b>			
Biomass (kg)	248,000,000	248,000,000	89,034,616
Yield (kg)	4,622,453	5,373,987	4,617,363
Total Spawn Biomass (kg)	99,103,903	106,301,600	82,568,416
Escapée Spawning Biomass (kg)	685,136	781,728	0
Total Escapes (number)	313,418	473,263	49,631
% Escapée spawners @ % Escapées	11.47%	11.85%	10.88%
Natural Fitness	0.9997	1.0000	0.9990
<b>Working Scenario 1 Simulations</b>			
Biomass (kg)	0.663,129	1,245,565	0
Yield (kg)	0	0	0
Total Spawn Biomass (kg)	2,473,054	3,543,093	0
Escapée Spawning Biomass (kg)	453,176	579,492	0
Total Escapes (number)	100,416	309,096	0
% Escapée spawners @ % Escapées	28.17%	1.18, 7.6%	10.00%
Natural Fitness	0.9997	1.0000	0.0000

### Species/ Scenario Management

Load Scenario

Save Scenario

Delete Scenario

Change Species Setting (Start Over)

Set Working Scenario as Reference Scenario

Reset Input Parameters to Reference Values

Reset Input Parameters (since last Run)

Undo Changes from Last Run (Go Back to Previous Run)

Last Run Time: 6 seconds, 03:34:40 PM Jul 13, 2012

Save Results Matrix File

OMEGA Version 1.01 July, 2012

### Settings/Preferences

Autosave on Close: OFF (SC)

Save OMEGA working state when saving scenario: OFF (SC)

Calculate on any change: OFF (SC)

Run once (TRUE) or run simulation: OFF (SC)

Number of Simulations: OFF (SC)

Apply Changes when reloading input parameters: OFF (SC)

Freeze Header Charts: OFF (SC)

Auto fit viewing area: OFF (SC)

Display Results from Previous Run: OFF (SC)

Go to Regulatory Module after Calculation: OFF (SC)

Use Random Variables in Simulations: OFF (SC)

Generate Results Matrix during Calculation: OFF (SC)

### Help

**\*\*\* Type Values in Yellow Cells. Cells of any other color contains output generated by OMEGA.**

**\*\* To zoom in on the Results Charts, click any chart in the Results to view it full screen.**

**\*\* Model interface is designed to fit a monitor resolution of 1024 by 768.**

**Quick Control Keys:**

Control + U (Apply): Using the current simulation random series, apply changes to OMEGA variables and recalculate

Control + R (Run simulate): Run a new OMEGA Simulation, apply changes to OMEGA variables and recalculate

**View Controls:**

Control + M: Reset OMEGA interface to best view at 1024 x 768 resolution

Control + Shift + F: Fit OMEGA interface in the current window

Control + W: Zoom current window to 75%

Control + I: Zoom in 5%

Control + O: Zoom out 5%

Control + F (page number): Show results chart in full screen

Control + D: Return to OMEGA Main view

## Scenario Types Displayed in OMEGA

The scenario types used in OMEGA are as follows:

- **Working Scenario:** The Working Scenario corresponds to the current set of parameter values being worked on in OMEGA. The parameter values in the yellow cells in all modules of OMEGA are associated with the Working Scenario. As parameter values are changed (and applied) in OMEGA, they modify the values in the Working Scenario. The heavy solid lines in the header charts correspond to the population response of the Working Scenario.
- **Reference Scenario:** The Reference Scenario is a Working Scenario with a population response that is locked into place on the header charts. OMEGA displays the population response of a Reference Scenario for comparison to the Working Scenario. The thin dashed lines in the header charts correspond to the Reference Scenario.
- **No Aquaculture Scenario:** The population response of the No Aquaculture Scenario is displayed on the charts to indicate the effect of no escapes being introduced into the natural population. Light solid lines in the header charts correspond to the No Aquaculture Scenario.
- **Previous Scenario:** The Previous Scenario allows a display of population response under the previous set of parameter values before hitting the *Apply* or *Run New Simulation* buttons. This function allows a comparison of results based on iterative changes to parameter values. The Previous Scenario also allows the user to back up one step from the last calculation, i.e., undo the previous calculation. The display of the previous scenario is optional.

The Scenarios Module allows the user to manage and choose which scenarios to display. Scenarios are discussed in further detail in the section *Using the Scenarios Module*.

## Adjusting the Viewing Area

When OMEGA opens, the program window will adjust to an optimal size for viewing on most overhead projectors (1024x768). The user can customize the program window via several methods:

### Zoom In/Out

To adjust the size of the viewing area in the active program window, use the key combination Ctrl + “[“ (left bracket) to reduce zoom value (zoom out), or Ctrl + “]“ (right bracket) to increase zoom value (zoom in).

### Fit View in Current Window

OMEGA can be fit to the active window for any screen resolution using the key combination Ctrl + Shift + F.

### Fit View for Overhead Projectors

The best fit view for overhead projectors is 1024 x 768. The viewing area can be reset to the default view using the key combination Ctrl + M. This also toggles the Excel full screen view which maximizes the window and shows/hides the toolbars and windows banner.

## Full Screen View for Header Charts

Any of the header charts can be shown full screen by using the key combination Ctrl + (the figure number). For example, to view Header Chart Figure 6 full screen, use the key combination Ctrl + 6. To return to the OMEGA main program screen, use the key combination Ctrl + O.

## Quick Start

This section contains a brief step-by-step guide describing how to load a dataset, vary model assumptions, and run simulations.

This step-by-step guide is based on one of the preloaded scenarios created for sablefish (*Anoplopoma fimbria*) and a hypothetical commercial aquaculture program along the Pacific coast of the United States. The scenario datasets included with the model were developed to test the model characteristics, sensitivity to assumptions and to demonstrate the model capabilities. In other words, the scenarios are not intended to reflect a proposed total production or an assessment of likely escapes from such an industry and should not be interpreted as an evaluation of potential impacts from a sablefish mariculture industry.

Quick Start consists of the following five steps:

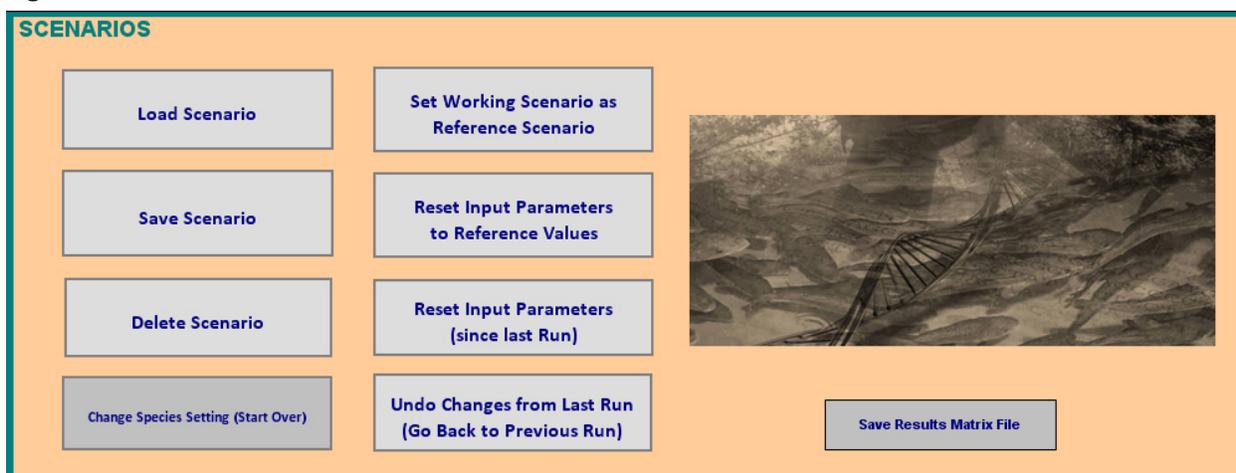
1. Load a scenario.
2. View results.
3. Change input values.
4. Save a scenario.
5. End a session.

These five steps are sufficient to get started to the point the information can be viewed/edited and a dataset can be saved. The user is strongly encouraged to review the entire guide once he/she is comfortable with the basic procedures outlined in this section.

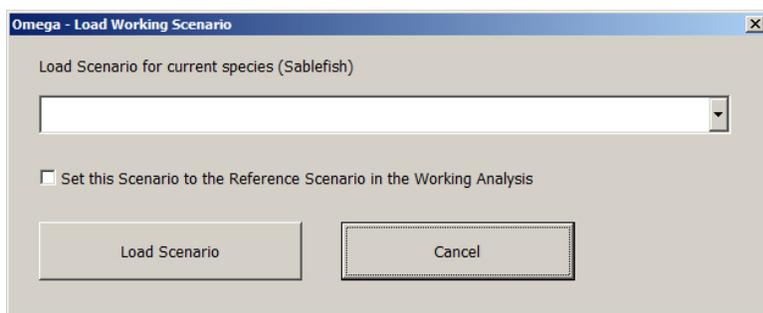
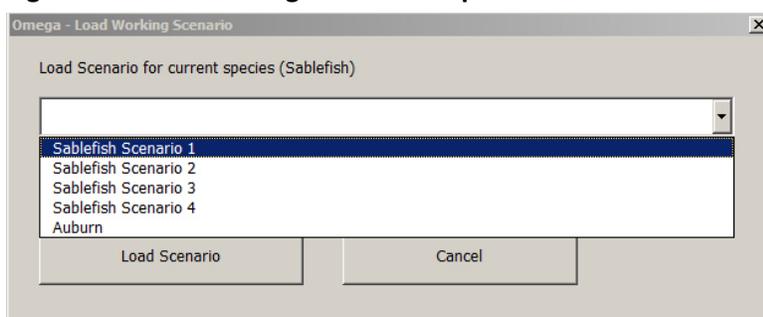
### Step 1. Load a Scenario

Perhaps the quickest way to load a scenario is to use one of the existing defined scenarios. Up to two scenarios can be compared at once, referred to in OMEGA as Reference Scenario and Working Scenario. Steps on how to change species, load a defined scenario, and build a model for a different species are presented in the Using the Scenarios Module section.

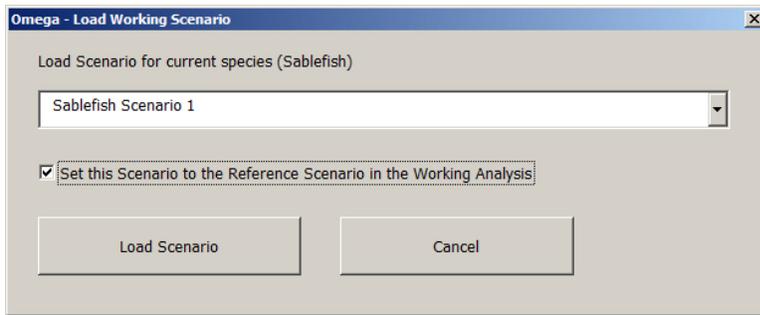
To load a scenario first from the Navigation Bar on the Header, click on the *Scenarios (Load/Save)* link to display the Scenarios Module (Figure 31). The Scenarios Module allows the user to manage and save working scenarios as they are developed in OMEGA. It also allows the user to recall work done on previously saved scenarios.

**Figure 31. Scenarios Module**

The first step to load a previously saved scenario is to click on the *Load Scenario* button in the upper left of the Scenarios Module. A dialog box will appear with a dropdown menu to select a scenario dataset (Figure 32). Clicking on the dropdown arrow will bring up a list of scenarios saved for sablefish (Figure 33).

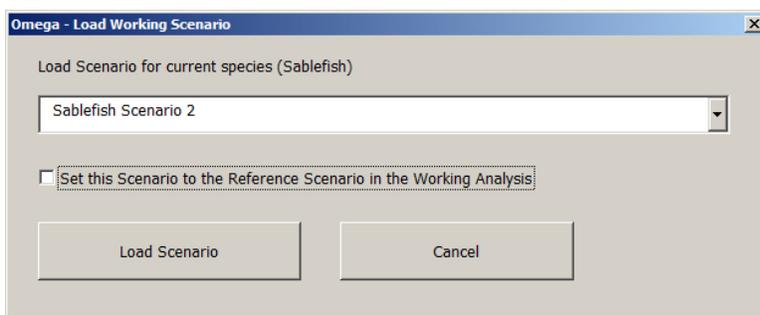
**Figure 32. Load Working Scenario Dialog****Figure 33. Load Working Scenario Dropdown Menu**

In this example, the user is selecting Sablefish Scenario 1. To compare this scenario to alternative model assumptions, the user needs to compare against a Reference Scenario. In this example, the user is setting Scenario 1 as the reference scenario by checking the box under the scenario dropdown menu. The completed form should look like Figure 34.

**Figure 34. Setting the Reference Scenario**

The final step is to click *Load Scenario*. Model inputs defined for Scenario 1 will load; OMEGA will run the calculations, update the results charts and tables, and set Scenario 1 as the Reference Scenario.

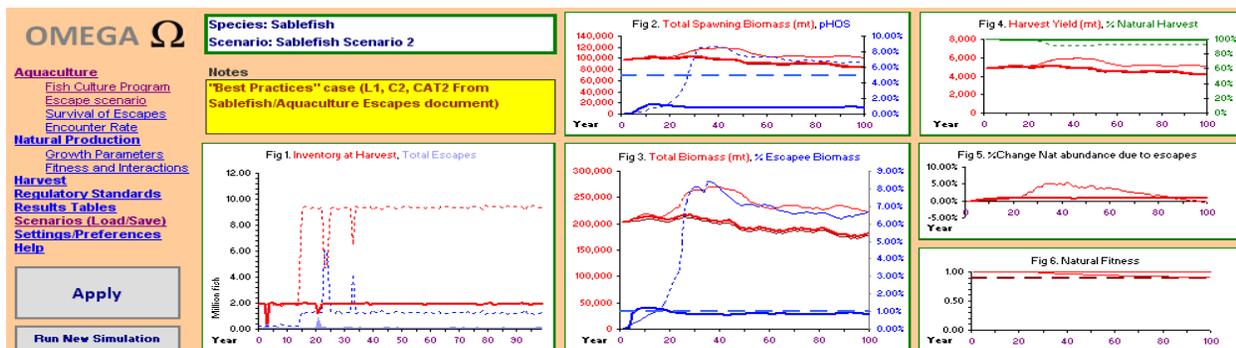
In this example, the user wants to compare model results for Sablefish Scenario 2 against Sablefish Scenario 1. To do that, the user selected the scenario Sablefish Scenario 2, but did not check the Reference Scenario checkbox (Figure 35). Doing this saves Scenario 1 as the Reference Scenario, and the results from Scenario 2 can be compared to those from the Reference Scenario. Upon clicking *Load Scenario*, OMEGA will once again run through the calculations for Scenario 2.

**Figure 35. Selecting a Scenario for the Working Analysis**

## Step 2. View Results

Once scenarios are loaded and calculations are complete, the header section of the main page will display results for Sablefish Scenarios 1 and 2 (Figure 36).

**Figure 36. OMEGA Results Charts for the Sablefish Scenarios 1 and 2**



There are six charts in the Header Section; each tracks different output from the simulation. The simulation results are charted from year 1 to year 100. The y-axis in each chart describes the particular metric computed in the simulation. In several charts a second y-axis is included to show a different, but related, metric in the same chart. Clicking on any chart in the Header Section will enlarge the chart to full-screen view and display the chart legend.

Results for the Reference Scenario (Sablefish Scenario 1 in this example) are shown as dashed lines, and the solid lines show results for the Working Scenario (Sablefish Scenario 2 in this example). Charts presenting population abundance and composition also include results for No Aquaculture. The No Aquaculture results are model results absent escapes. The red lines (dashed and solid) reference the primary y-axis. Blue and green lines reference the secondary y-axis.

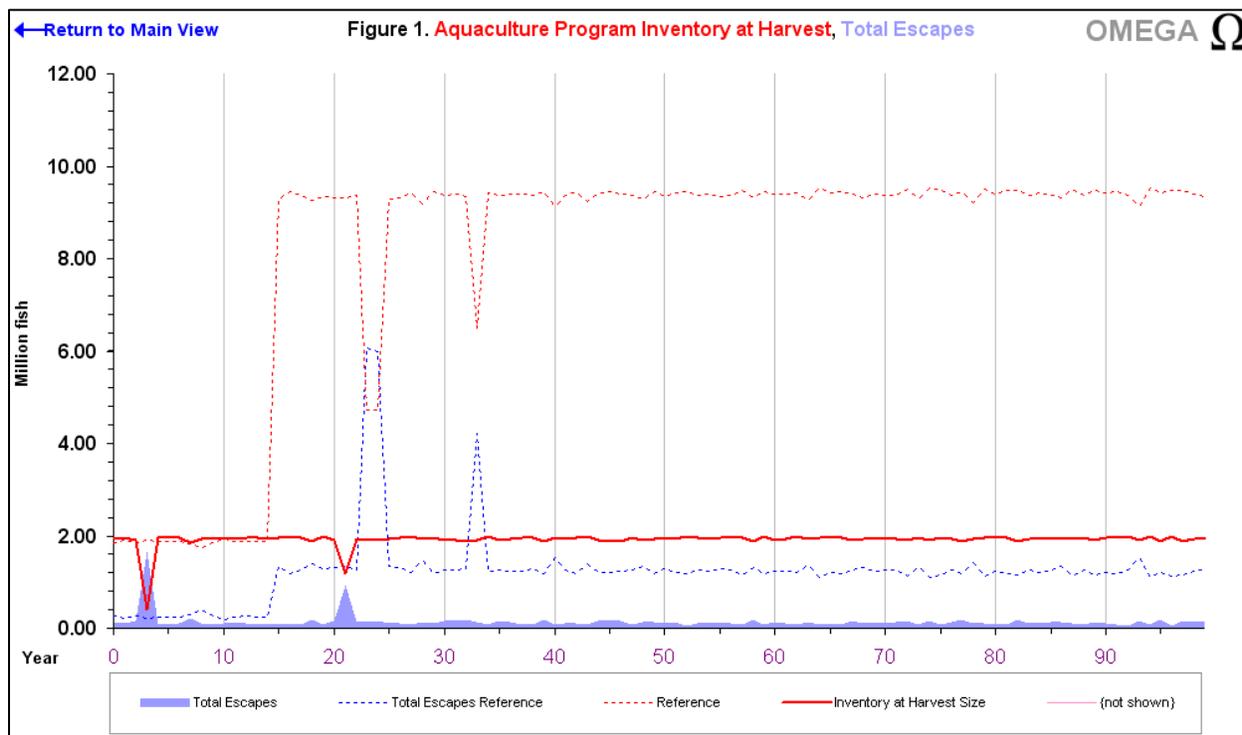
As shown in Figure 36, Sablefish Scenario 2 is currently selected. Each of the six header charts shown in Figure 26 is discussed below, using the simulation results from the hypothetical Sablefish Scenario 2 as an example.

## Aquaculture Inventory and Escapes

Figure 37 (Header Chart Figure 1) contains two series plotted over a 100-year simulation period: the aquaculture program inventory at the time fish are harvested and brought to market, and the total number of escaped fish from an aquaculture program. In this example, the total number of escapes under the Working Scenario is shown as an area series. The Reference dotted line series refer to the Reference Scenario (Sablefish Scenario 1), against which the Working Scenario (Sablefish Scenario 2) can be compared to determine how parameter changes between the Working Scenario and Reference Scenario affected the analysis. In this chart, the total escapes series from the Reference Scenario is shown as a blue dashed line.

In this example, the aquaculture program inventory in the Working Scenario (solid red line series) is about 2 million fish per year, while under the Reference Scenario (dashed red line series), the program began at year 1 with an inventory of 2 million fish (2,000 mt), and expanded to about 10 million fish (10,000 mt) in year 16. The spikes in the Reference Scenario indicate the year where large losses from the program occurred in the simulation. In this example, for the Reference Scenario at around year 22, the program realized a loss of about half its inventory, resulting in a commensurate rise in escaped fish for that year.

**Figure 37. OMEGA Results Shown in Header Chart Figure 1**



## Natural Stock Spawning Biomass and Composition

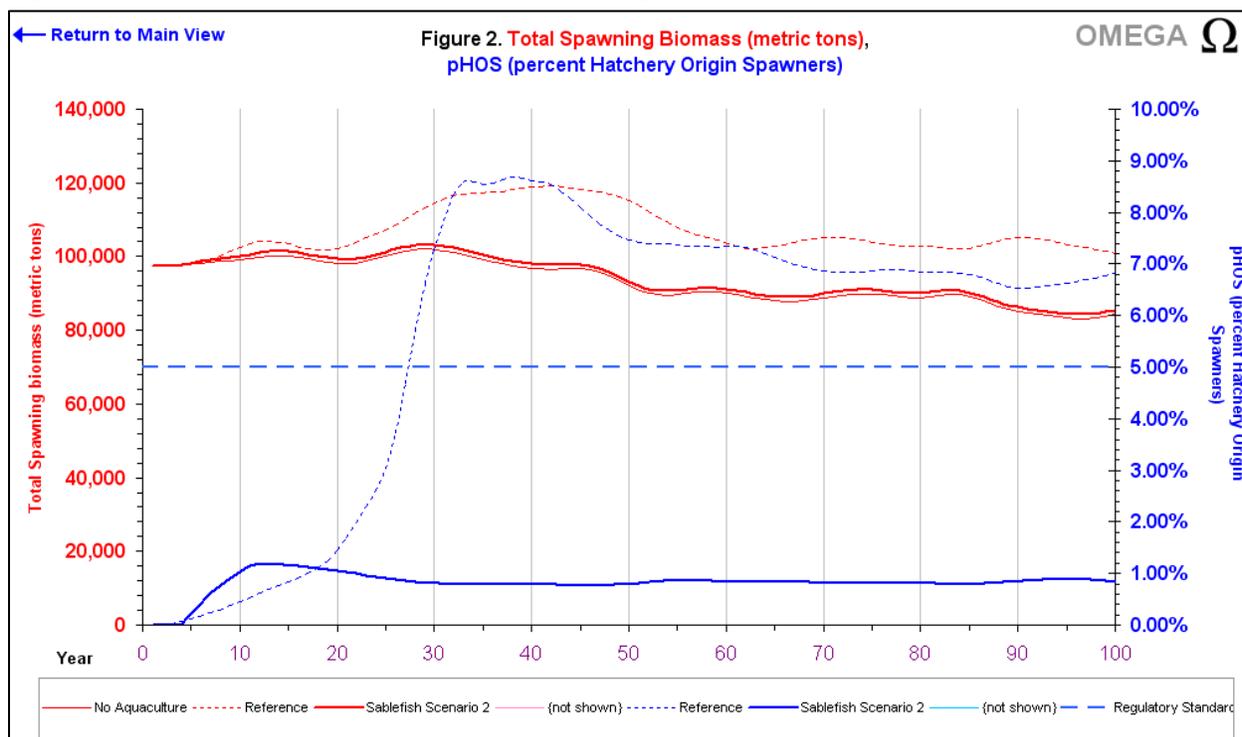
Figure 38 is one of three header chart figures (Header Chart Figures 2, 3, and 4) that includes a secondary axis. The chart figure series corresponds with the font color of the axis. Note that the legend indicates series for *No Aquaculture*, *Reference* and *Sablefish Scenario 2* that are red lines with different line styles. The *No Aquaculture* series refers to the Working Scenario, subtracting the influence of the aquaculture program. *Reference* is the Reference Scenario, the fixed version of the Working Scenario defined by using one of the functions of the Scenarios Module. *Sablefish Scenario 2* is the Working Scenario. There is another series

labeled “{not shown}”, which corresponds to the *Previous* results of the calculations. If this feature is turned on under the Settings/Preferences Module, this series would also show on the charts.

The series *Reference* and *Sablefish Scenario 2* also appear in the legend for the series on the blue axis, using the same line styles as the primary axis. A *No Aquaculture* series does not appear on the secondary axis in this case, because under the no-aquaculture condition the fish of hatchery (or culture) origin always equals zero. Finally, the regulatory standard (set by the user in the Regulatory Standards Module) appears as a blue series to indicate a standard on the secondary axis. In this example there is a hypothetical regulatory limit of 5% for hatchery origin spawners in the total spawning population abundance (this hypothetical limit is used for model illustration purposes only, and is not intended to describe existing or planned regulatory standards). The 5% limit was chosen because it represents a point that fitness is more strongly affected by escapees using assumptions for spawning success and selection strength applied to the sablefish scenarios.

As shown in Figure 38, the red line series on the primary axis refers to the total spawning biomass, and the blue line series on the secondary axis refers to the percent Hatchery Origin Spawners in the population abundance (pHOS), corresponding with the chart title. In this example, total spawning biomass is lower under the Working Scenario starting in about year 8, compared to the Reference Scenario. Under the Reference Scenario, the pHOS line exceeds the pHOS regulatory standard starting in year 28 of the program, ending at a little below 7% in year 100. Under the Working Scenario, the program was modified resulting in a decreased pHOS with a maximum of about 1% starting in year 10.

**Figure 38. OMEGA Results Shown in Header Chart Figure 2**



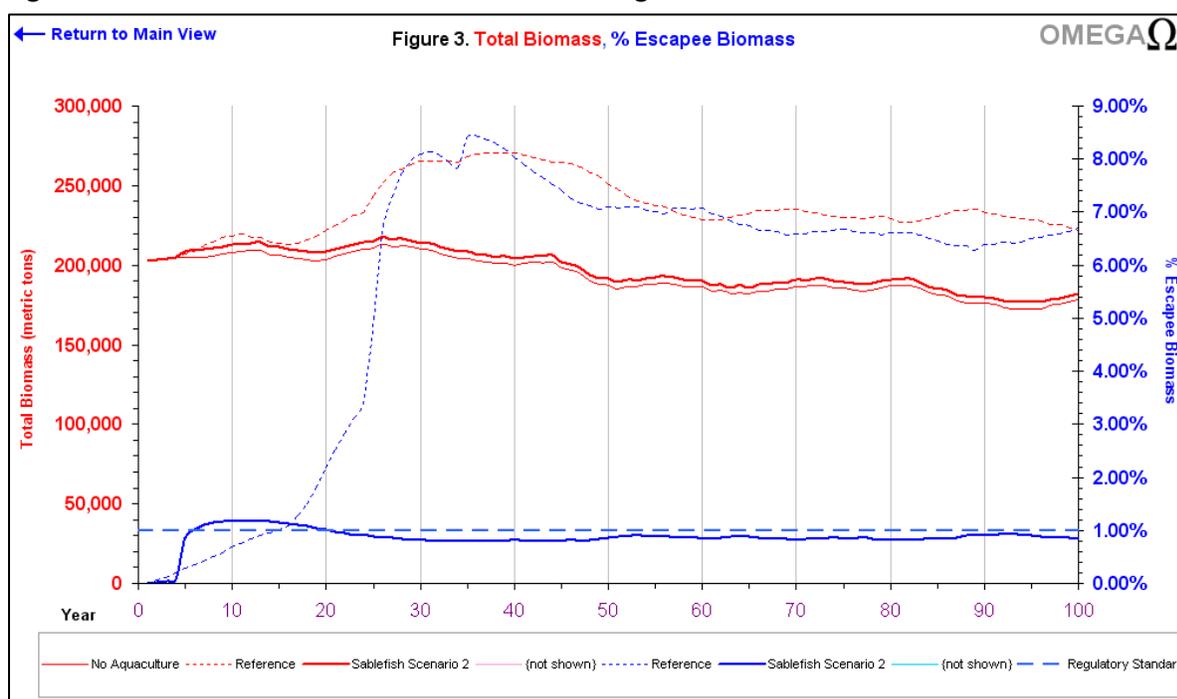
## Natural Stock Biomass and Composition

Figure 39 includes a secondary axis. This chart is similar to Figure 38 discussed previously, except that the series shown in Figure 39 corresponds to the total biomass and the escapee composition in the biomass. The series on the charts corresponds with the font color of the axis. The legend indicates a series for *No Aquaculture*, *Reference* and *Sablefish Scenario 2* that are red lines with different line styles. The *No Aquaculture* series refers to the Working Scenario, subtracting the influence of the aquaculture program. *Reference* is the Reference Scenario, the fixed version of the Working Scenario defined by using one of the functions of the Scenarios Module. *Sablefish Scenario 2* is the Working Scenario.

The series *Reference* and *Sablefish Scenario 2* also appear in the legend for the series on the blue axis, using the same line styles as the primary axis. A *No Aquaculture* series does not appear on the secondary axis in this case, because under the no-aquaculture condition the percent of escapes always equals zero. Finally, the regulatory standard (set by the user in the Regulatory Standards Module) appears as a blue series to indicate a standard on the secondary axis. In this example, there is a hypothetical regulatory limit of 1% for the escapees in the total biomass (this hypothetical limit is used for model illustration purposes only, and is not intended to describe existing or planned regulatory standards). The 1% limit was chosen in this example as it roughly corresponds to the 5% limit for hatchery spawners based on post escape survival assumptions in the sablefish scenarios.

As shown in Figure 39, the red line series on the primary axis refers to the total biomass, and the blue line series on the secondary axis refers to the percent of escapees in the biomass. Under the Reference Scenario, the percent of escapees Reference line (the blue dashed line) exceeds the regulatory standard starting in year 16 of the program, ending at a little below 7% in year 100. Under the Working Scenario, the program was modified resulting in a decreased escapee composition, with a maximum of about 1% starting in year 10, marginally meeting the regulatory standard.

**Figure 39. OMEGA Results Shown in Header Chart Figure 3**



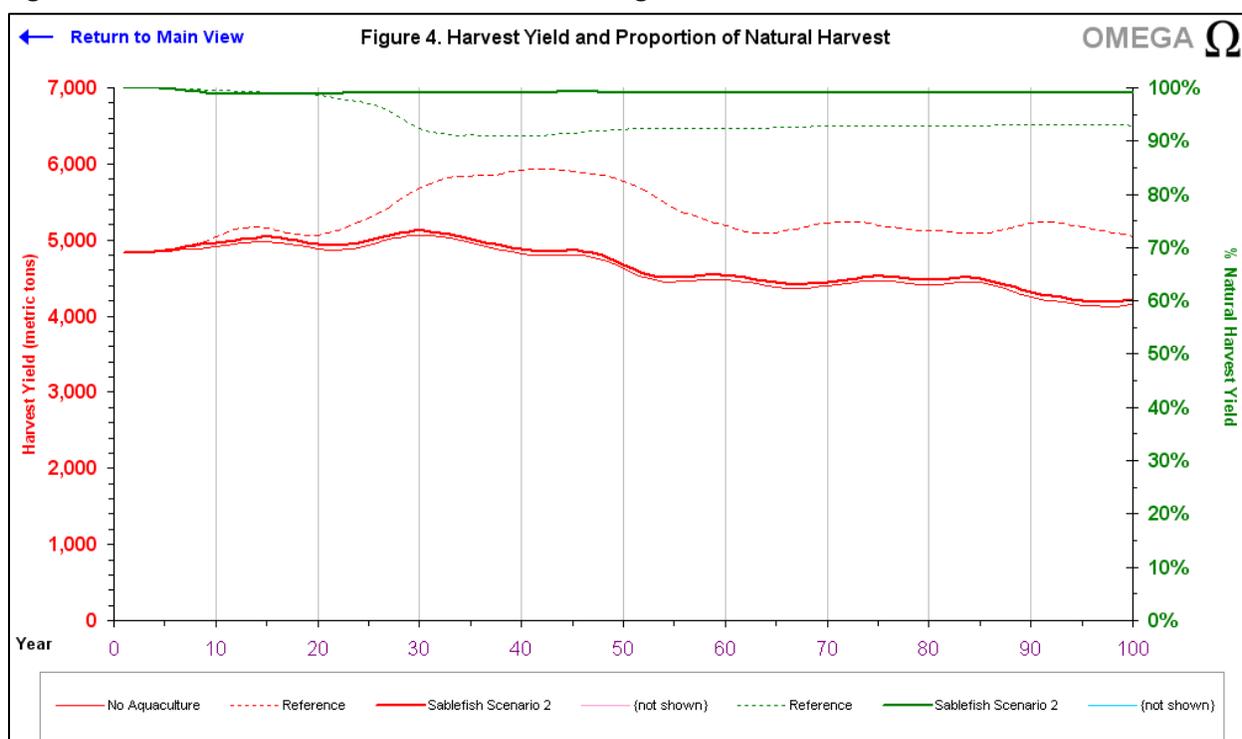
## Natural Stock Harvest Yield and Composition

Figure 40 also includes a secondary axis. The series on the charts corresponds with the font color of the axis. The legend indicates a series for *No Aquaculture*, *Reference* and *Sablefish Scenario 2* that are red lines with different line styles. The *No Aquaculture* series refers to the Working Scenario, subtracting the influence of the aquaculture program. Reference is the Reference Scenario, the fixed version of the Working Scenario defined by using one of the functions of the Scenarios Module. *Sablefish Scenario 2* is the Working Scenario.

The *Reference* and *Sablefish Scenario 2* series also appears in the legend for the series on the green secondary axis, using the same line styles as the primary axis. A “*No Aquaculture*” series does not appear on the secondary axis in this case, because under the no-aquaculture condition the percent of natural harvest yield equals 100%.

The red line series on the primary axis in Figure 40 refers to the harvest yield, and the green line series on the secondary axis refers to the percent of escapees in the biomass. Under the Working Scenario, harvest yield (solid bold red line series) decreases slightly on average over each year of the 100-year simulation from about 5,000 to just over 4,000 metric tons in year 100, and percent of natural fish harvested is slightly below 100% for all years. Under the Reference Scenario, harvest yield increases starting in about year 20, while the composition of natural fish decreases to a value of about 93% in year 100.

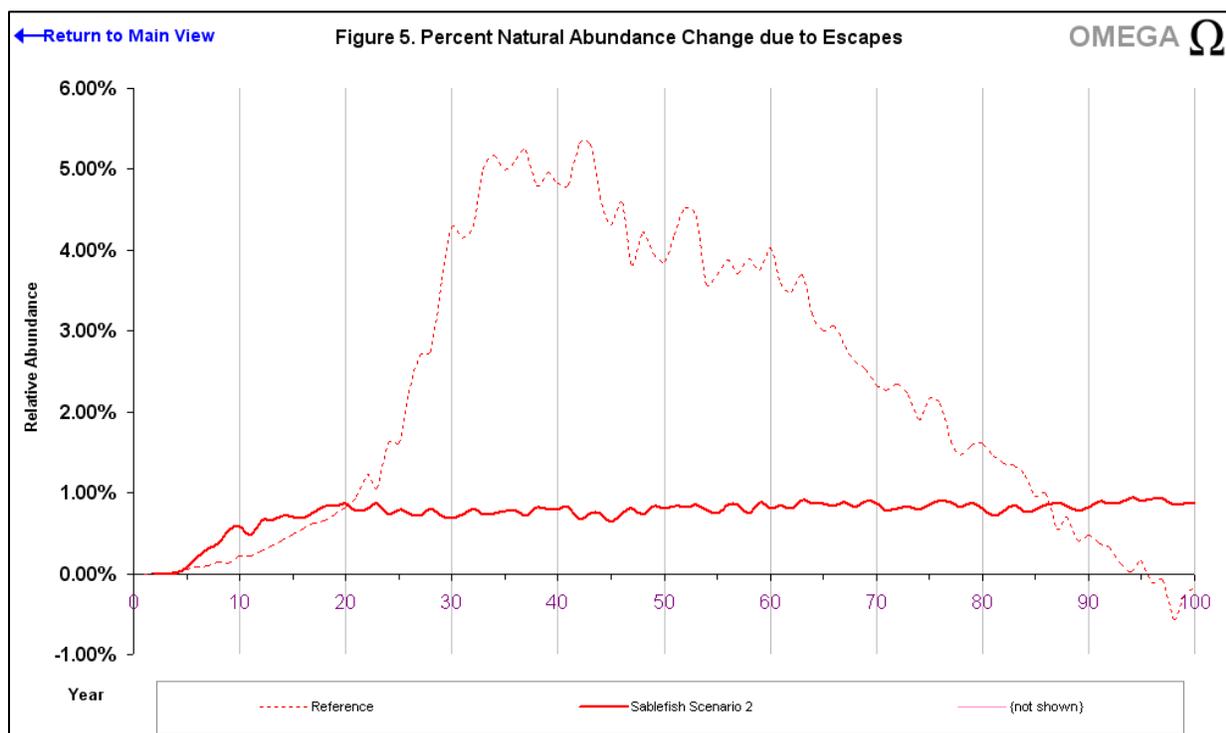
Figure 40. OMEGA Results Shown in Header Chart Figure 4



## Change in Abundance of Natural Stock (Fish Born in Nature)

Figure 41 plots the abundance trends in natural fish due to the presence of the aquaculture program. Under the Reference Scenario, a high number of escaped fish are introduced into the system starting in about year 20. Recall in Figure 37 that the aquaculture program expanded starting in year 16. The program losses occurring after the expansion resulted in a large increase in natural abundance, followed by a decline in the natural population, dipping below baseline/no aquaculture levels (0%) in about year 95. Under the Working Scenario *Sablefish Scenario 2*, natural abundance increases to about 1% over baseline abundance by year 20, and stays within that range through year 100. It is helpful to look at this chart in conjunction with natural fitness trends over time, shown in Figure 42.

**Figure 41. OMEGA Results Shown in Header Chart Figure 5**

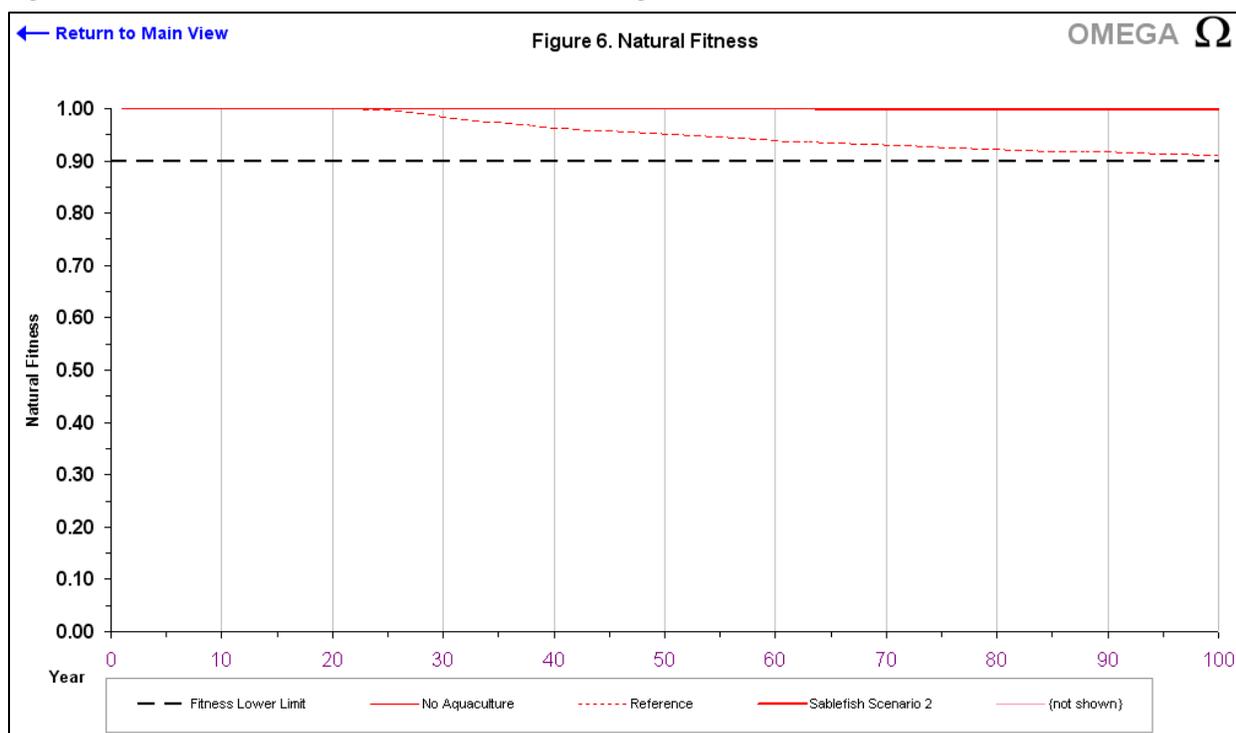


## Trend in Natural Stock Genetic Fitness

As shown in Figure 42, natural fitness begins to decline steadily in year 23 under the Reference Scenario, to a value of about 0.91 in year 100. This is marginally above the hypothetical fitness lower limit of 0.90, indicated on the chart by a bold dashed black line. Under the Working Scenario, natural fitness remains within a range of 0.99 to 1.00 through the 100-year simulation.

Reviewing the results of these charts (Figure 37 through Figure 42) together; it is possible to study relationships between parameters, and the natural population response to the presence of escapees in the wild.

**Figure 42. OMEGA Results Shown in Header Chart Figure 6**



## Step 3. Change Input Values

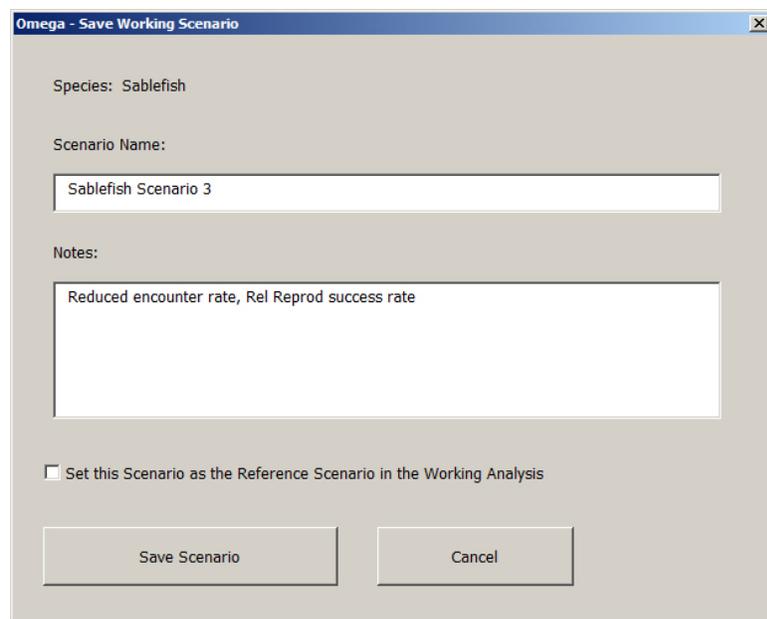
OMEGA is now ready to run different inputs to compare against the Reference Scenario and the *No Aquaculture* condition. The Navigation Bar in the Header Section is used to select the modules of interest to change settings. A description of each module (Figure 39) follows the Quick Start section of this guide.

## Step 4. Save a Scenario

To save work at the end of a modeling session you must save a scenario. Saving writes the model inputs to a worksheet in the OMEGA Excel file. Scenarios are saved by clicking on the *Scenario (Load/Save)* item in the Navigation Bar and then clicking *Save Scenario* in the Scenarios Module.

A dialog box will appear asking for inputs for scenario name and descriptive notes (Figure 43). Click *Save Scenario* to write the scenario inputs for storage and future retrieval.

**Figure 43. Save Scenario Dialog Box**

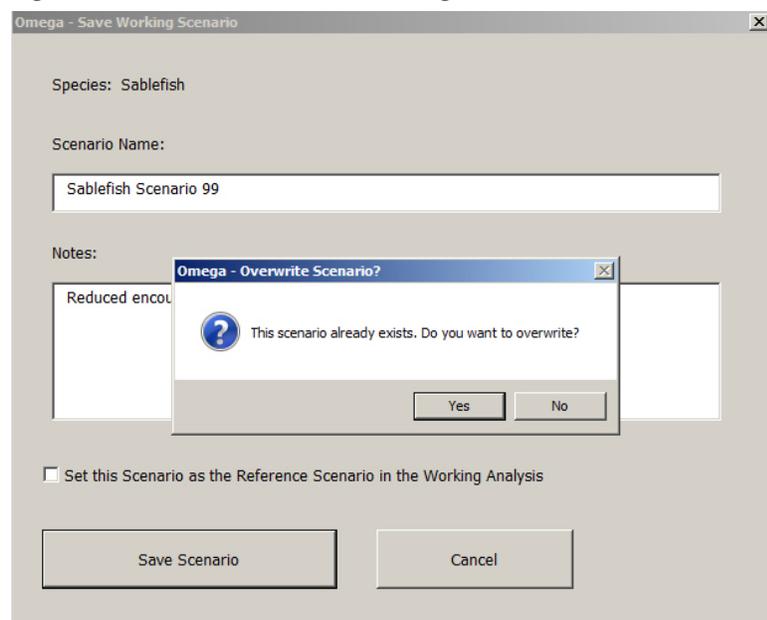


### Important Note

**Important Note** each module denote cells for user inputs. After a user has revised an input, then click the Apply button to run a new simulation. The choice of clicking *Apply* or *Run New Simulation* depends on whether the user desires to run the model with fixed randomization (*Apply*) or run the model with new randomization (*Run New Simulation*). Clicking *Apply* after revising an input parameter will fix the randomization and any response in model results will be entirely due to the revised input. Clicking *Run New Simulation* will include a revised randomization in the results. Thus a comparison of results will include the effect of the revised input and effect of randomization.

If the scenario name entered corresponds to the name of a dataset previously saved in OMEGA, then the user will be prompted to confirm replacement of the parameter values in the existing scenario (Figure 44).

**Figure 44. Overwrite Scenario Dialog**



To update the parameter values in the existing scenario, select *Yes* to overwrite. To cancel, click *No*.

Congratulations! The scenario is now saved and available for use as a Reference Scenario for future modeling sessions.

## Step 5. Ending a Session

The OMEGA Excel file contains all the scenario information, so remember to save OMEGA (Ctrl + S) before closing Excel. This step is needed to preserve the changes made to the OMEGA scenarios.

The following sections add more detail about using OMEGA, including additional discussion about features discussed above in the Quick Start section.

# Using the Scenarios Module

## Working with Scenarios in OMEGA

OMEGA has the capability to remember sets of parameter values, i.e., scenarios, which can be recalled later during any OMEGA work session. These scenarios preserve the working state of OMEGA in a given work session. Scenarios enable the user to compare one set of parameter values to another. For example in the previous Quick Start discussion, two scenarios were discussed: Sablefish Scenario 1 and Sablefish Scenario 2.

In the example, the work session began with a Scenario 1 as a Reference Scenario and worked with Scenario 2. These were created by loading Scenario 1 and setting it as the Reference Scenario, then saving a new scenario (Sablefish Scenario 2) and revising parameters in this scenario to evaluate response relative to Scenario 1.

As described in the Quick Start section, the Scenarios Module contains all functions dealing with scenarios in OMEGA, and is accessible from the Navigation Bar in the OMEGA model Header Section (Figure 45).

**Figure 45. Navigating to the Scenarios Module**

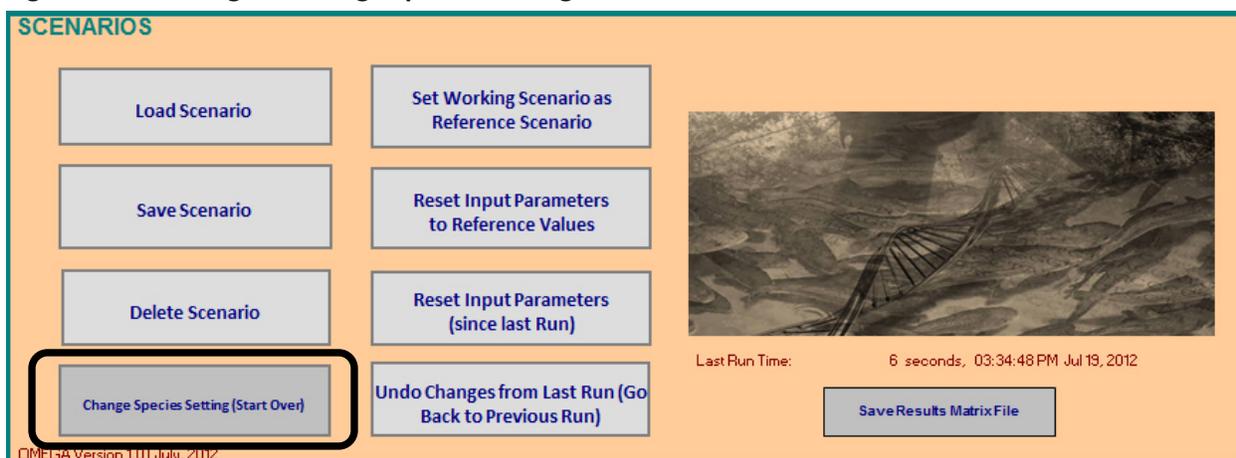


In addition to loading and saving scenarios, the Scenarios Module contains several useful functions that allow the user to customize the presentation of population responses under one or more scenarios. The organization and display of scenarios in OMEGA is discussed in more detail under the Viewing Results section. Users should make sure they are working with the desired species before selecting a scenario.

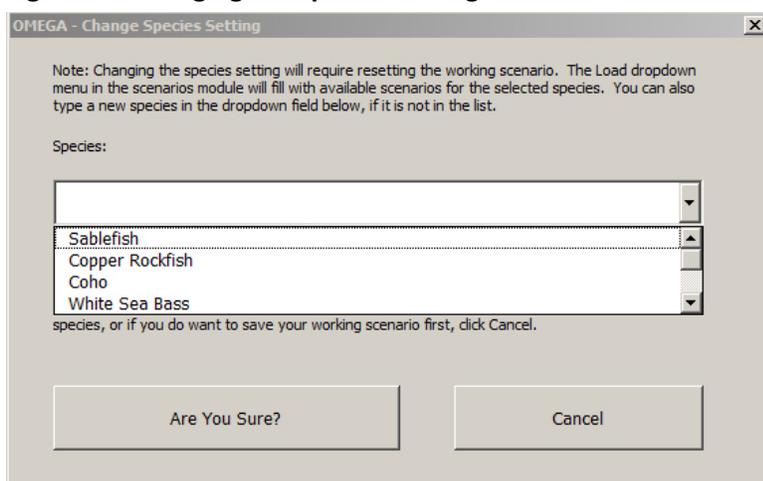
## Selecting a Species

The species in the current analysis is shown in the upper left of the Header Section in OMEGA (Figure 28). Examples detailed in this user guide are for sablefish. Version 1.0 also includes inputs for a rockfish species to demonstrate how to setup OMEGA for more than one species.

To change between species the user clicks the corresponding button in the Scenarios Module (Figure 46).

**Figure 46. Selecting the Change Species Setting in the Scenarios Module**

In this example the user wants to load scenarios for rockfish. Clicking the *Change Species Setting* button will bring up a dialog box with a dropdown menu list with species included in OMEGA Version 1.0 (Figure 47).

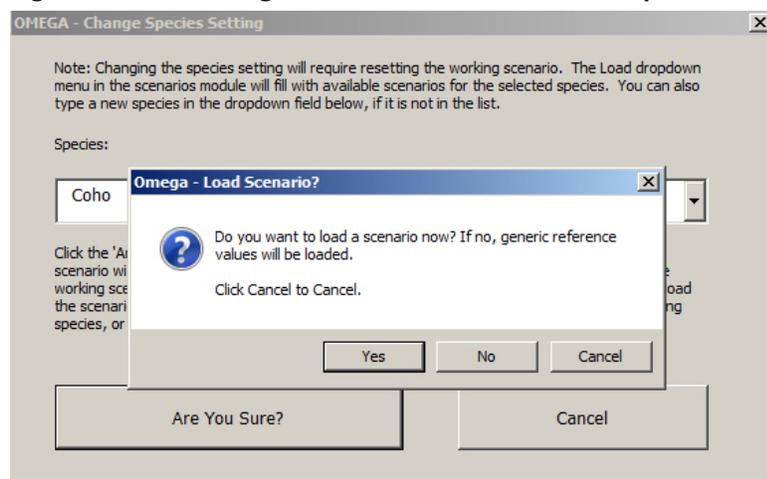
**Figure 47. Changing the Species Setting**

Selecting a species will filter the available scenarios in OMEGA to those for that species. The scenario list that was previously filtered for scenarios related to sablefish will now be filtered by scenarios related to rockfish.

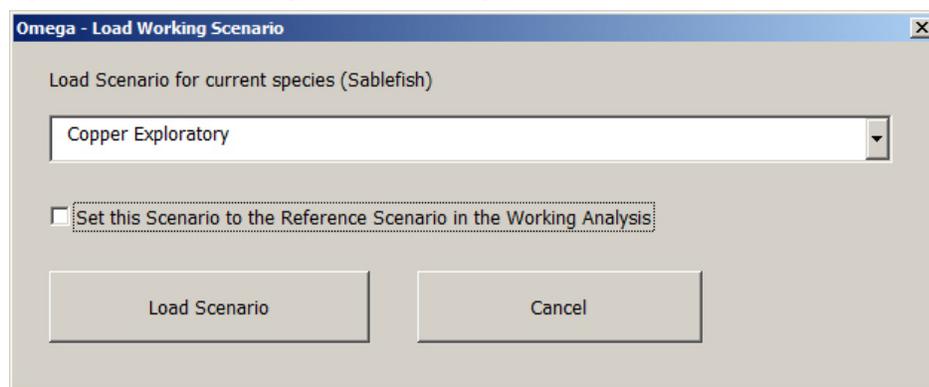
The user also has the option of typing a new species name into the dropdown menu field. If this is the desired approach, make sure that the species does not already appear in the dropdown list.

To continue, click the *Are You Sure?* button. This will overwrite the Working Scenario with the new input values. If you are not sure, click *Cancel* to back out of the steps and preserve your analysis in the Working Scenario, by going through the Save Scenario steps.

If the user continues the steps to add a new species to OMEGA, another dialog box will appear asking if the user wants to load inputs using an existing set of assumptions (Figure 48).

**Figure 48. Associating a Scenario with the Selected Species**

This dialog allows the user to indicate a set of parameters to be associated with the currently selected species. Generally, it may be useful to use a previously saved scenario as a starting point for a new analysis. Clicking the Yes button will allow the user to select a previously saved scenario to associate with the selected species. That dialog is similar to the scenario list that appears in the Load Scenario dialog, except that it is not filtered by species (Figure 49). Figure 49 depicts the working scenario dialog. The dropdown menu includes all scenarios available to the user for analysis of the selected species.

**Figure 49. Load Working Scenario Dialog**

In this case the user selected Copper Exploratory, which was previously developed for copper rockfish, as a starting point. There is also the option to load generic parameter values, if no information of any kind is available in OMEGA for the species. However, it is probably useful in most cases to choose data that was developed under a previous scenario for the species as a starting point for a new analysis.

To complete the process of selecting a species and a scenario as the basis for the analysis, click *Load Scenario*. Make sure the Reference Scenario checkbox is checked to update the reference scenario for the currently selected species.

If *No* was selected in the dialog box for loading a scenario (Figure 48) then OMEGA would load a generic set of values for all parameters (based on an early developed sablefish scenario). This was provided as an example parameter set to begin modeling. If this generic scenario is used, the user should carefully review all

parameters in the scenario and update values for the species being modeled. Click *Cancel* to abandon the process of changing the species setting and return to the OMEGA main view.

## Setting a Reference Scenario

There are three functions related to setting a Reference Scenario in OMEGA:

- Loading a previously saved scenario and setting it as the reference point,
- Setting the Working Scenario as the Reference Scenario, and
- Setting parameter values in the Working Scenario to the values from the Reference Scenario.

## Loading a Previously Saved Scenario and Setting it as the Reference Point

This function was also discussed in the Quick Start section. The steps are repeated here. First click on *Load Scenario*. A dialog box appears, prompting the user to select a different scenario for the species.

The next option is to set this as a Reference Scenario effectively making it a temporary standard against which a user can compare a Working Scenario.

The last step is to click *Load Scenario*. The parameter values for the selected scenario will load for the Working Scenario as well as the Reference Scenario. As parameter values are changed, the Reference Scenario response will be preserved, while the response for the Working Scenario will change reflecting modifications to parameter values. The user can then make comparisons between model responses for each scenario to evaluate the effects of parameter value changes.

## Setting the Working Scenario as the Reference Scenario

This function may be useful if the user wants to create a new point of reference for comparison purposes. It is also useful if the Reference Scenario is not meaningful to the current analysis, and the user wishes to remove it from the charts. The Working Scenario can be converted to a Reference Scenario in an analysis by setting it as the new reference point. This makes the Reference Scenario equal to the Working Scenario. Then the user can compare a new Working Scenario going forward to this new reference point.

Select *Set Working Scenario as Reference Scenario* in the Scenarios Module. The user will then be prompted to confirm that setting as a new reference point, which will remove the current reference point and set it to the Working Scenario.

Note that the Reference Scenario appears to vanish from the charts in the Header Section, but in fact, the Working Scenario now overlays the Reference Scenario. Going forward with the analysis, this new Reference Scenario will be visible again in the charts as the Working Scenario diverges from this new reference point.

## Setting Parameter Values in the Working Scenario to the Values from the Reference Scenario

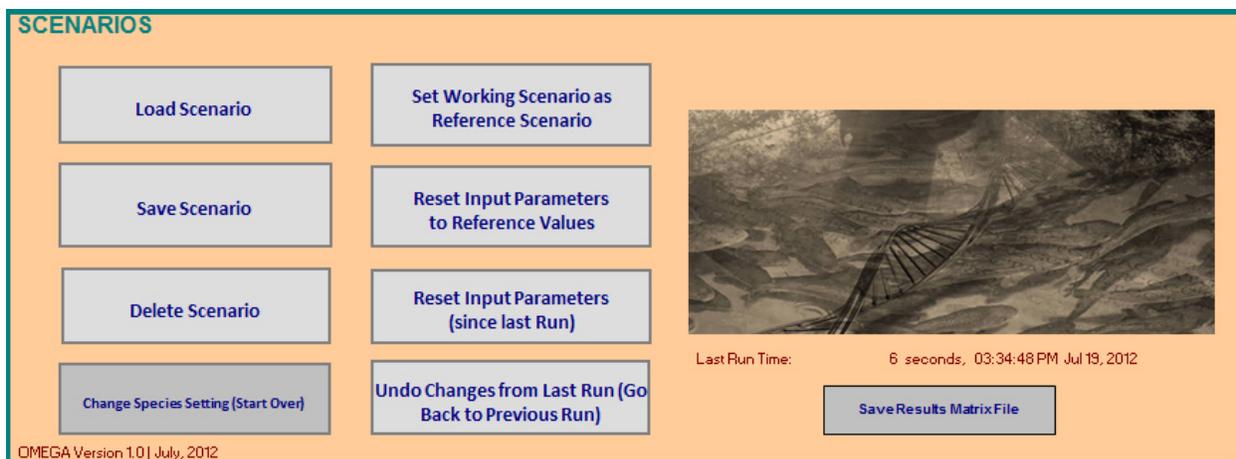
This function is the reverse of the process previously described. Selecting *Reset Input Parameters to Reference Values* is a way for the user to restore parameter values from the Reference Scenario used for

the analysis. This is an effective way to start an analysis from the beginning, if a working analysis is moving in the wrong direction, or changes to the working analysis are becoming too difficult to track.

## Undo Functions

The Scenarios Module also contains three functions for undoing changes made to the Working Scenario (Figure 50).

**Figure 50. Undo Functions in the Scenarios Module**



The undo functions are as follows:

1. Setting Parameter Values in the Working Scenario to the Values from the Reference Scenario.
2. Resetting Input Parameters since the last Run (Apply or Simulation).
3. Undo Changes from the Last Run, or return to parameters used in the Previous Run.

## Setting Parameter Values in the Working Scenario to the Values from the Reference Scenario

This function allows the user to return from the Working set of parameter values to the Reference set of parameter values. This process is the third item discussed in the previous section.

## Resetting Input Parameters since the Last Run

This function allows the user to undo all changes to parameters since the last calculation run. This function is useful if the user desires to save the last calculated state as a scenario but earlier forgot, or if a set of wrong numbers was typed into the input parameter fields. However, this will undo all changes since the last calculation. As long as there are not too many parameter changes, this may be a useful function.

## Undo Changes from the Last Run, or return to parameters used in the Previous Run

This function is useful if it is desired to save the previous set of parameters as a scenario. This function is also useful where it is desired to undo the parameter changes from the last calculation (perhaps because results are going in an undesired direction). Returning to the Previous Run makes this possible.

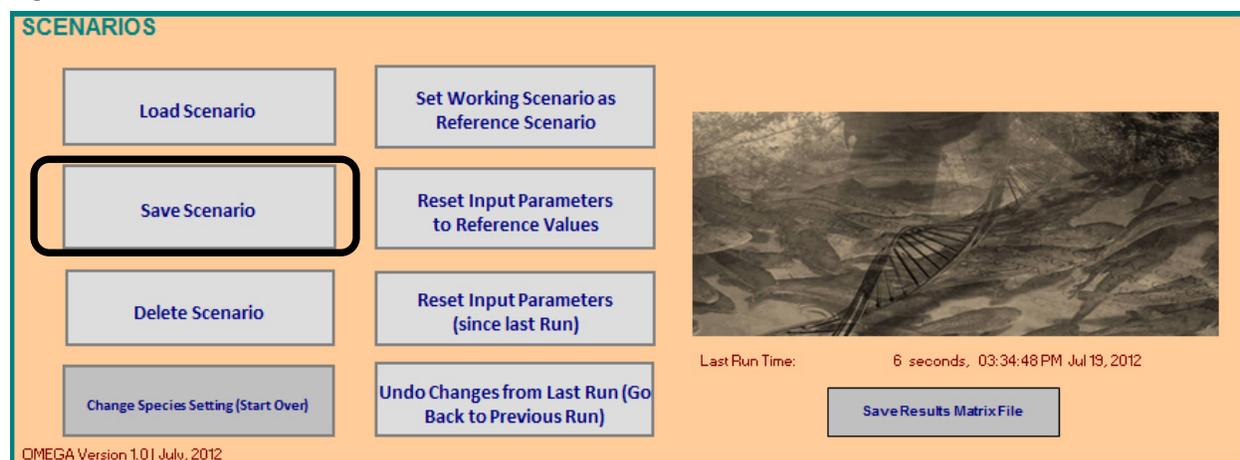
## Saving Scenarios

The Working Scenario can be saved by clicking on the *Save Scenario* button in the Scenarios Module, as shown in Figure 51.

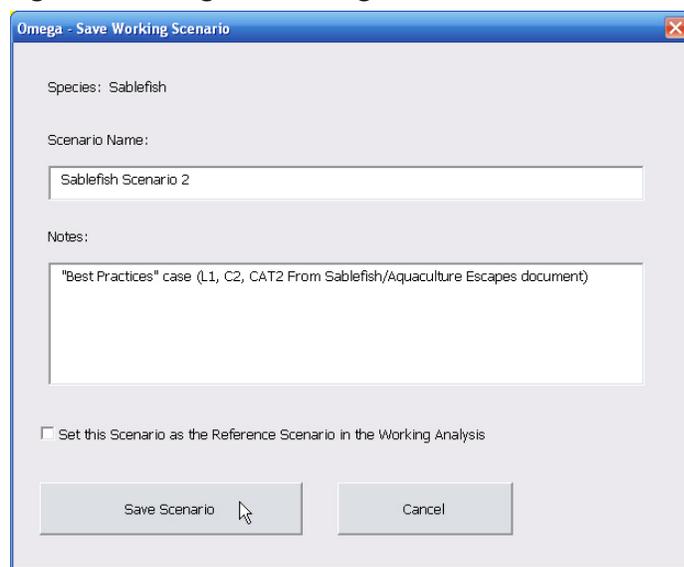
**Important Note**

Saving a Scenario does not involve saving a file external to OMEGA. The scenario is remembered within OMEGA, and becomes integral to the program. It is better to think of “saving” a scenario as “remembering” the scenario. Therefore, the scenario can only be remembered if the OMEGA application itself is saved after a work session. There is a setting under Settings/Preferences that allows the user to specify whether OMEGA should “Save OMEGA working state when saving scenarios”. By default this is set to true, so whenever a scenario is saved, OMEGA is also saved, thus OMEGA will remember the scenario you just saved after closing the program. One instance of OMEGA can remember up to 999 individual scenarios across all species.

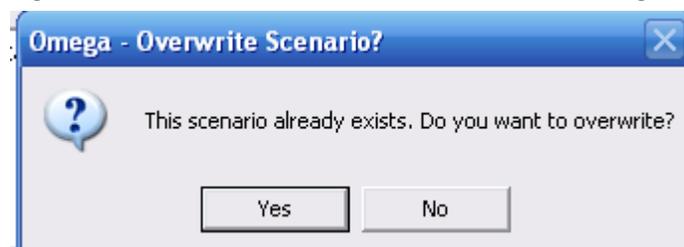
**Figure 51. Save Scenario Button**



This example involves the Sablefish Scenario 2 scenario. Clicking *Save Scenario* will display the dialog in Figure 52.

**Figure 52. Saving the Working Scenario**

The Working Scenario name, Sablefish Scenario 2 is shown in the dialog. The dialog also captures the notes taken while conducting the analysis. If desired, further changes can be made to the notes in this dialog, or the name of the scenario can be changed. In this case the Sablefish Scenario 2 scenario will be updated with the work just completed. To do this, click the *Save Scenario* button in the Scenarios Module. A message then appears (Figure 53).

**Figure 53. Overwrite Parameter Values of an Existing Scenario**

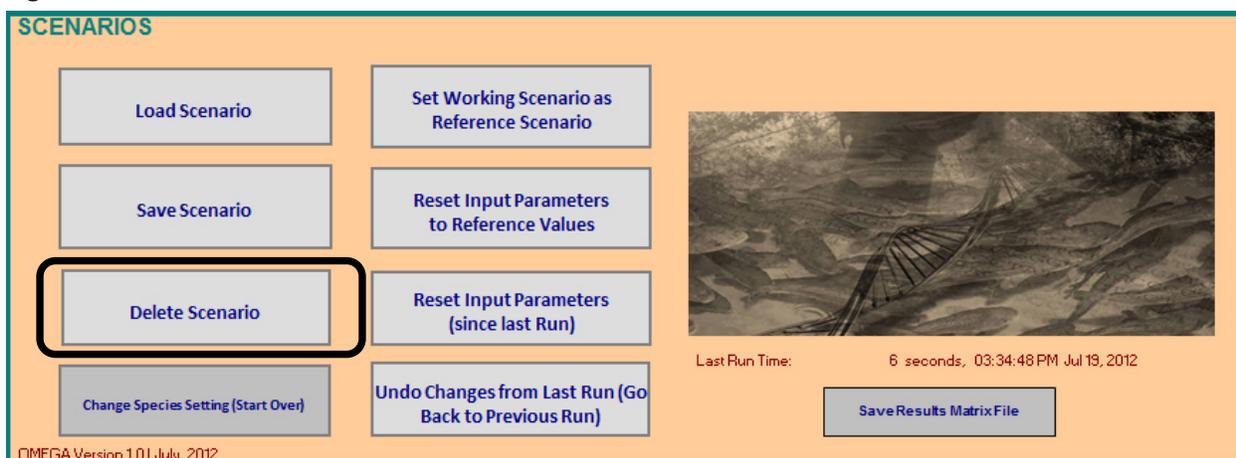
Click *Yes* to update the parameters in Sablefish Scenario 2. (Clicking *No* will cancel the save.)

As shown in Figure 52, the user also has the option to set the scenario as the Reference Scenario, if desired. It has the same effect as selecting the *Set Working Scenario as Reference Scenario* button discussed earlier.

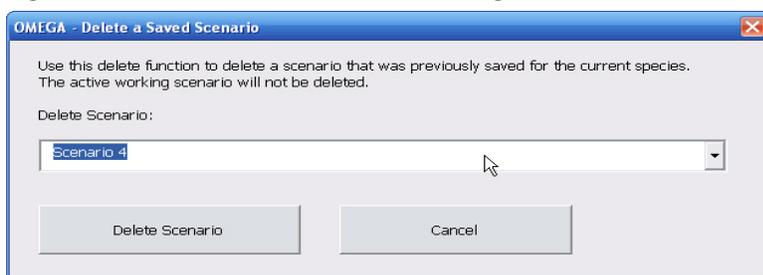
Working in this fashion, the user can save as many sets of parameters as desired, thereby facilitating an approach to designing scenarios toward a goal of achieving desired outcomes.

## Deleting Scenarios

Finally, the user can delete scenarios that are no longer useful by clicking the *Delete Scenario* button (Figure 54).

**Figure 54. Delete Scenario Button**

The Delete Scenario dialog appears (Figure 55). This function will allow the user to delete a scenario for the currently selected species. It will not delete the Working Scenario (i.e., the scenario currently loaded on the screens).

**Figure 55. Delete a Saved Scenario Dialog**

In this example the user selected Scenario 4 as the scenario to delete. Clicking *Delete Scenario* will delete the scenario; there is not a follow up dialog, so the user should be sure this is what is desired before proceeding.

## Save Results Matrix File

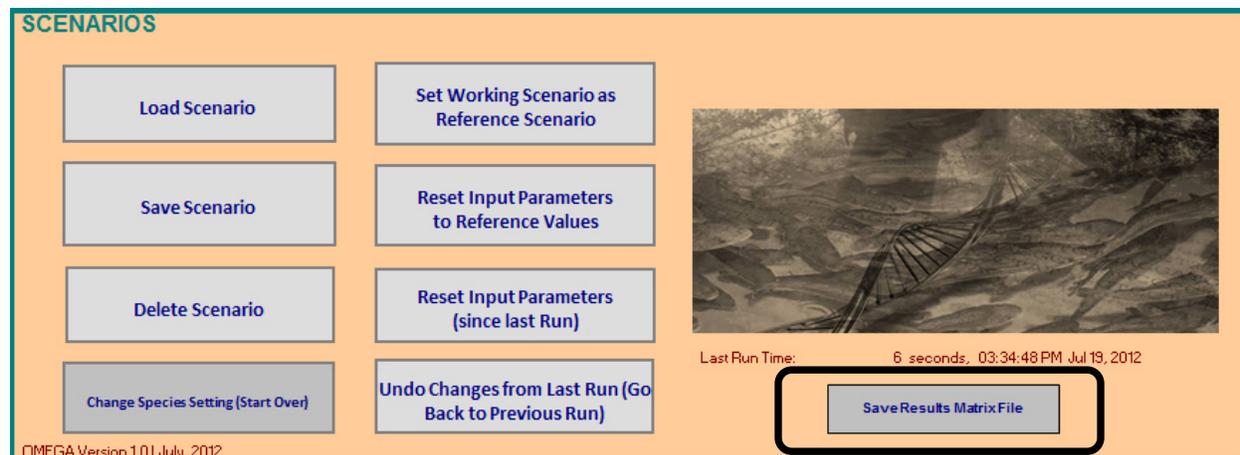
OMEGA has the capability to generate an output table of population age classes by year of program. If the setting *Generate Results Matrix during Calculation* (found under Settings/Preferences) is set to TRUE, this function is available. The results matrix contains the following parameter values:

- Fecundity by age,
- Proportion of mature females by age,
- Productivity by age,
- Capacity by age,
- Age at end of recruitment period,
- Fishing mortality by age,
- Female spawning biomass by program year,

- Wild abundance by age and program year,
- Wild and escape abundance by age and program year,
- Simulated program escapes by bin size and program year, and
- Brood year fitness by program year.

This information can be saved into an external Excel format file for review. Click on the *Save Results Matrix File* button in the Scenarios Module (Figure 56).

**Figure 56. Save Results Matrix File Button**



This action will bring up an Excel save dialog that will allow the user to save the results matrix in a separate Excel file in the normal fashion. The default file name for the file is Results\_{time stamp in yymmddhhmmss format}.xls.

## The Header Section of OMEGA

This section discusses elements shown in the upper half of the screen in the OMEGA main view. As discussed earlier, the Header Section contains the Navigation Bar which allows the user to select modules of interest in OMEGA, including the Scenarios Module discussed in the previous section. The Header Section is shown in Figure 57.

Figure 57. The Header Section of OMEGA



## Running Calculations in OMEGA

For each calculation, OMEGA runs a 100-year simulation of natural- and hatchery-origin population characteristics, based on all age classes of natural-origin fish and escaped fish that survive in the wild. Each calculation can take up to a minute to complete, depending on the computing speed of the machine running OMEGA. For this reason, OMEGA does not automatically recalculate for every change made in the analysis. Calculations are run by clicking either the *Apply* or *Run New Simulation* buttons, shown in the Header Section in Figure 57.

The choice of clicking *Apply* or *Run New Simulation* depends on whether the user desires to change the random characteristic of the simulation. Both buttons run the 100-year simulation described above; the difference is in how variability is applied to the calculation. OMEGA calculations contain a random number component to simulate how population response varies over time. The degree of variability depends on the settings of parameters such as coefficients of variability for Natural Production, and escape probabilities for Escape Scenarios. The *Apply* button holds the set of random numbers that contributed to the population response in the previous calculation. The *Run New Simulation* button creates a new set of random numbers to calculate the population response.

The *Apply* button is useful to study how changes in parameter values affect population response, to allow a visual sensitivity analysis of relationships between input parameters (changes to parameter values in modules) and model output (charts in the Header Section). This is where the comparison between the Reference and the Working Scenario in the header charts becomes most informative, as demonstrated in the Quick Start section (and discussed later in this section).

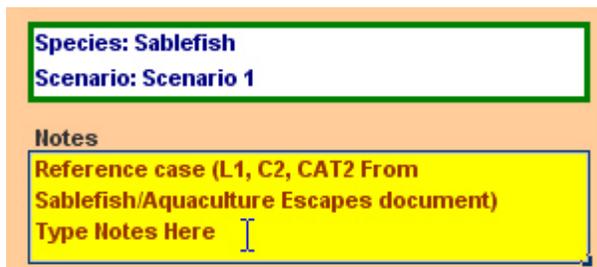
In general, it is suggested that a given analysis should start by clicking the *Run New Simulation* button, and then clicking the *Apply* button as parameter values are changed to study the direct effect of those changes on population response.

The calculation functions can also be accessed by key combinations: Ctrl + U for *Apply* and Ctrl + R for *Run New Simulation*.

## Entering Notes about a Scenario

In OMEGA, the user can type data into any of the yellow cells. That includes the Notes box in the Header Section (Figure 58). The Species and Scenario section is an indicator of the current species and scenario, and does not accept user changes to text. The text in the Species and Scenario section is modified when the user saves a scenario (see the Saving Scenarios section).

Figure 58. Species and Scenario Indicator and Notes Box



## Header Charts

The six header charts display the calculation results. The user can click on any of these charts for a full screen view. A detailed discussion of the contents of these charts is provided in the Quick Start section.

A full screen view of Header Chart Figure 3 is shown in Figure 59.

Figure 59. OMEGA Header Chart

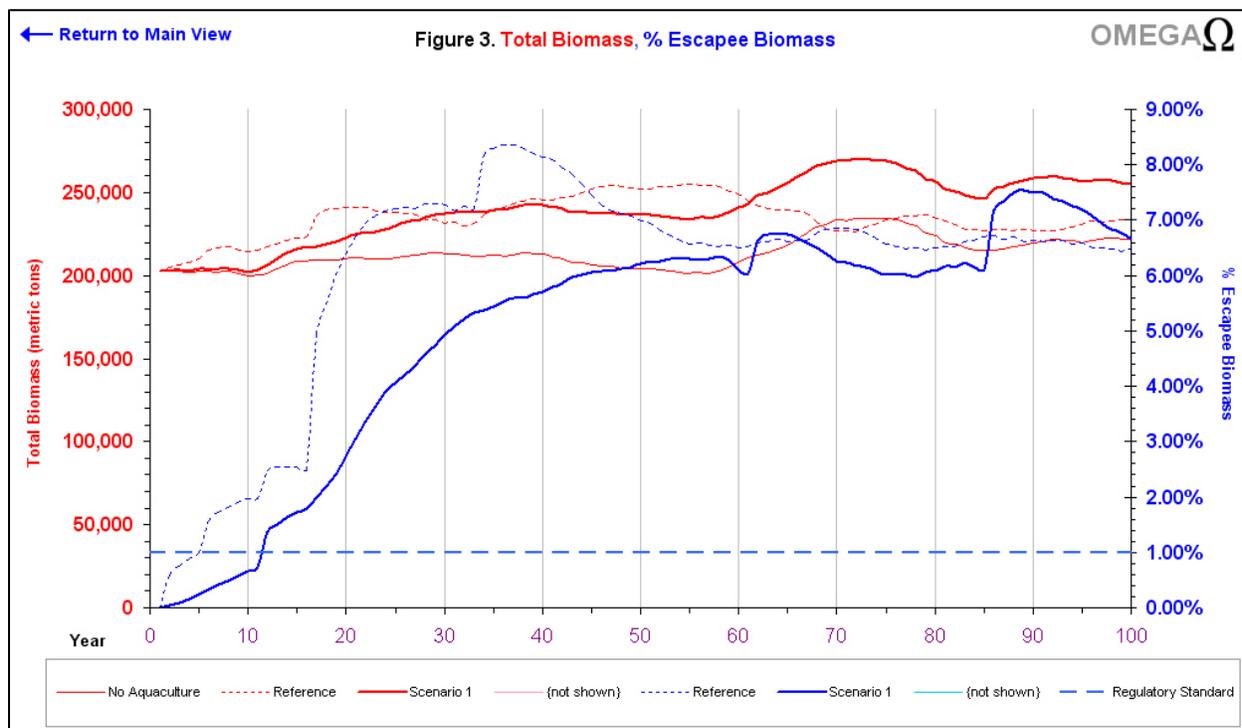


Figure 59 (Header Chart Figure 3) is one of three header charts (Header Chart Figures 2, 3, and 4) that include a secondary axis. The series on the charts correspond with the font color of the axis. Note that the legend

indicates series for No Aquaculture, Reference and Scenario 1 that are red lines with different line styles. The No Aquaculture series refers to the Working Scenario, subtracting the influence of the aquaculture program. Reference is the Reference Scenario, the fixed version of the Working Scenario defined by using one of the functions of the Scenarios Module. Scenario 1 is the Working Scenario, which was given the name shown in Figure 65. There is another series labeled “{not shown}”, which corresponds to the “Previous” results of the calculations. If this feature is turned on under the Settings/Preferences Module, it would also show on the charts.

The series Reference and Scenario 1 also appear in the legend for the series on the blue axis, using the same line styles as the primary axis. A No Aquaculture series does not appear on the secondary axis in this case, because under the no-aquaculture condition the percent of escapes always equals zero. Finally, the regulatory standard (set by the user in the Regulatory Standards Module) appears as a blue series to indicate a standard on the secondary axis. In this hypothetical case there is a regulatory limit of 1% for composition of escapes in the total biomass. The 1% limit was chosen in this example as it roughly corresponds to the 5% limit for hatchery spawners based on post escape survival assumptions in the sablefish scenarios.

Viewing the charts full screen allows the user access to the ability to see the underlying values of the data points. Simply click on the series of interest, and hover the arrow over the data point to reveal its value.

To return to the OMEGA main screen, click in the upper left or upper right areas of the chart, or use the key combination Ctrl + O.

Some calculation results are also summarized in tabular form (see the Results Tables Module) and can also be viewed in matrix form by age and year in a separate file (see Save Results Matrix File in the Scenarios Module section).

## OMEGA Modules

This section describes how users interact with the model and set parameter values. A detailed background of the parameter types contained in these modules is discussed in the Model Overview. Many parameter types are self-explanatory. The modules are briefly introduced here, with guidance for using some of the key parameters.

All OMEGA modules are accessed via the navigation links in the Header Section of the OMEGA main screen.

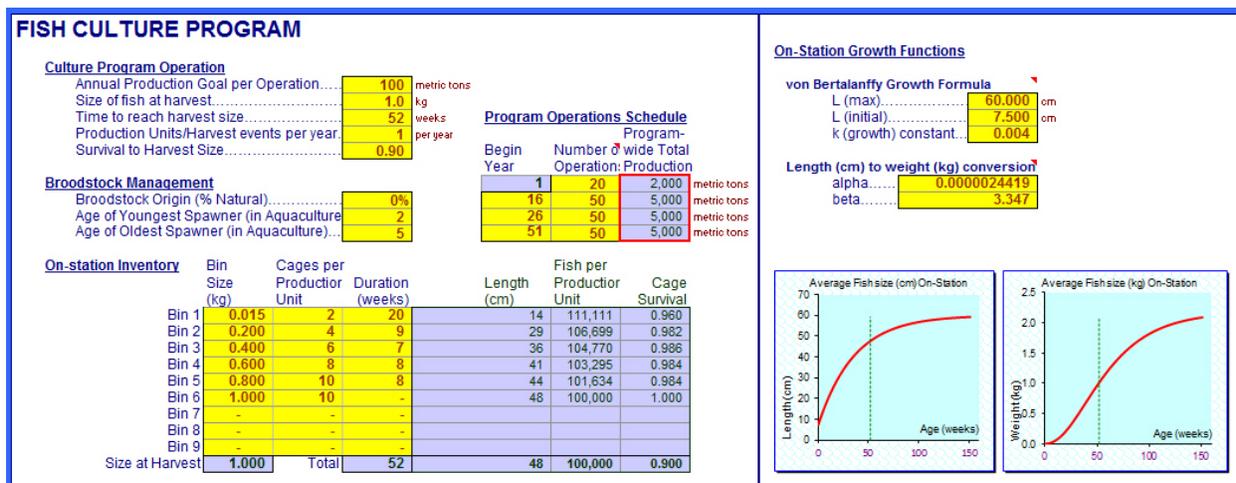
### Fish Culture Program

The Fish Culture Program Module is shown in Figure 60. This module contains the aquaculture parameters related to the design of the fish culture program, including bin sizes on station and harvest goals. Parameters include:

#### Culture Program Operation

The annual production goal is indicated in metric tons. The production units/harvest events parameter refers to the number of times fish are harvested during the year. The annual production goal is divided by the number of harvest events to determine the size of the harvest in metric tons at each event. This, in turn, affects how fish are distributed in size bins throughout the year.

**Figure 60. Fish Culture Program Module**



### On-Station Inventory

Up to nine bin size categories can be entered, each with a number of offshore cages per production unit that correspond to the bin size, and duration in weeks that fish grow in the bin until they graduate to the next size bin. Note that the “size at harvest” fish should be included in the largest size bin, as shown in Figure 60. Also, the sum of the durations across all size bins should equal the time to reach harvest size. If they do not, a warning message will appear below the inventory table. Unused bin sizes can be zeroed out.

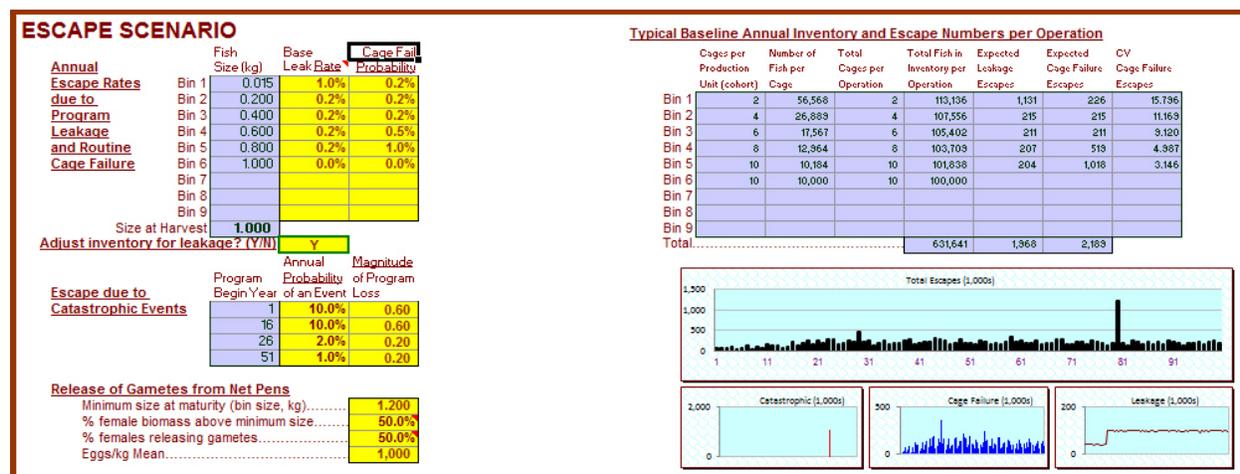
### Program Operations Schedule

The function of the schedule is to describe the overall size of the total program or aquaculture industry of interest. The program consists of a number of individual operations or farms growing 100 metric tons of fish to market size annually. Total program size is a scaling factor to the single operation described under Culture Program Operation. Using operations as the unit of the program, the example in Figure 60 shows that, in year 1 until year 16, the total program consists of 20 operations, for a program-wide total production of 2,000 metric tons. In year 16, the program is scheduled to increase to 50 operations or farms, with a total production of 5,000 metric tons.

### Escape Scenario

The Escape Scenario Module is shown in Figure 61. The Escape Scenario is not to be confused with user-defined scenarios designed in the Scenarios Module. Parameters shown in the example are to illustrate inputs and are not intended to describe a particular scenario.

Figure 61. Escape Scenario Module



The Escape Scenario Module contains parameters related to mechanisms of fish escape from the aquaculture program. Escapement characteristics are assumed to be uniform across operations in the aquaculture program. Parameters include

- Annual Escape Rates due to Operation Leakage and Cage Failure,
- Adjusting inventory for leakage, and
- Escape due to Catastrophic Events

## Annual Escape Rates due to Program Leakage and Routine Cage Failure

The Base Leak Rate addresses the assumption that fish escape from cages due to factors unrelated to the failures in infrastructure. It should be assumed here that each bin size may lose a percentage of fish annually. The Cage Failure Probability is not a rate of leakage, but a probability that any cage in the corresponding bin size category will fail over the course of a given year.

## Adjust Inventory for Leakage

The *Adjust Inventory for Leakage?* parameter is a toggle switch to indicate that the program will adjust the inventory in each bin size based on the indicated leak rate, in order to meet the harvest goal for the program. If the switch is set to Y, each operation will be modeled to yield the annual production goal. If set to N, the operation will be modeled on the basis of the production goal being met using the requisite number of eggs, ignoring the effects of fish escaping from the program.

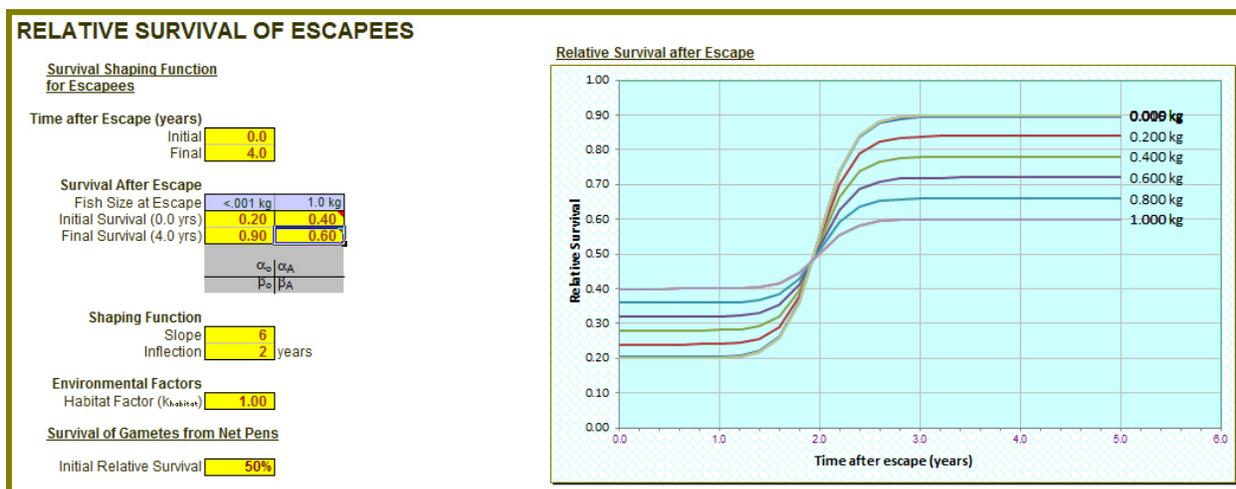
## Escape Due to Catastrophic Events

The table for catastrophic events corresponds to the Program Operations Schedule. As the program is scaled over time, it is possible to adjust the annual probability of a catastrophic event as well as the magnitude of program loss (the fraction of fish in the program that escape, across bin sizes).

## Relative Survival of Escapees Module

This module contains parameters to describe the shape of the survival curve for escaped fish, with time zero as the time of escape. Survival after escape is described by smallest and largest size survival rates (Figure 62). The habitat factor is an environmental variable that affects initial survival in the vicinity of the program. Initial relative survival for gametes from pens is applied to gamete survival in natural.

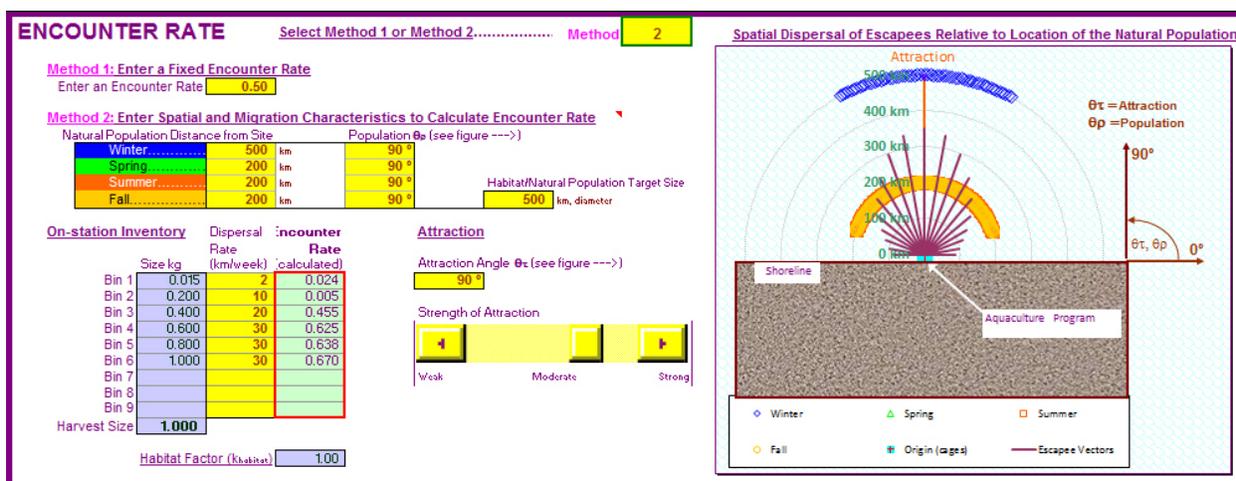
Figure 62. Relative Survival of Escapees Module



## Encounter Rate

The Encounter Rate Module contains parameters related to the rate of escapes surviving to encounter wild conspecifics. The user should first select *Method 1* or *Method 2* as shown in Figure 63, to determine whether the encounter rate is specified as a fixed value, or calculated based on spatial and migration characteristics.

Figure 63. Encounter Rate Module



When Method 1 is selected, the user specifies the encounter rate, which is held constant across the bin size categories in the aquaculture program, and all parameters under Method 2 are ignored.

Method 2 is provided for demonstration purposes as a qualitative way to estimate encounter rate based on spatial and environmental factors. When Method 2 is selected, the spatial component of encounter rate is based on the habitat/natural population target size and the distance from site. The graphic shown in the Encounter Rate Module is a way to visualize how escapes from the aquaculture program disperse (thick lines are escapee vectors) and the proximity of escapee vectors to habitat/natural population targets (thick arcs for winter, spring, summer and fall migration distances).

The probability that escapees will encounter wild conspecifics depends on relative survival, and dispersal rate, or speed that escapees travel from the cage facility into open water, in terms of straight-line distance from the facility. The direction and distribution of vectors are adjusted using the attraction angle and strength of attraction controls. The strength of attraction is a qualitative component to describe how escapees disperse in the direction of an attraction force, such as a current, specified as the attraction angle  $\theta\tau$ , which is set independently of the habitat/natural population target angle  $\theta\rho$ . The calculated encounter rate differs by bin size and is displayed in the on-station inventory table of the Encounter Rate Module after each calculation, when Method 2 is selected.

## Natural Production and Natural Growth Parameters

The Natural Production and Natural Growth Parameters Modules contain natural population and recruitment characteristics for wild conspecifics. The modules contain shaping functions to describe spawner recruitment, natural survival, size by age, and mature females by age. The Natural Production Module also includes coefficients of variation to describe variability of egg production, recruitment, and survival over time. The Natural Production and Growth Parameters modules are shown in Figures 64 and 65.

Figure 64. Natural Production Module

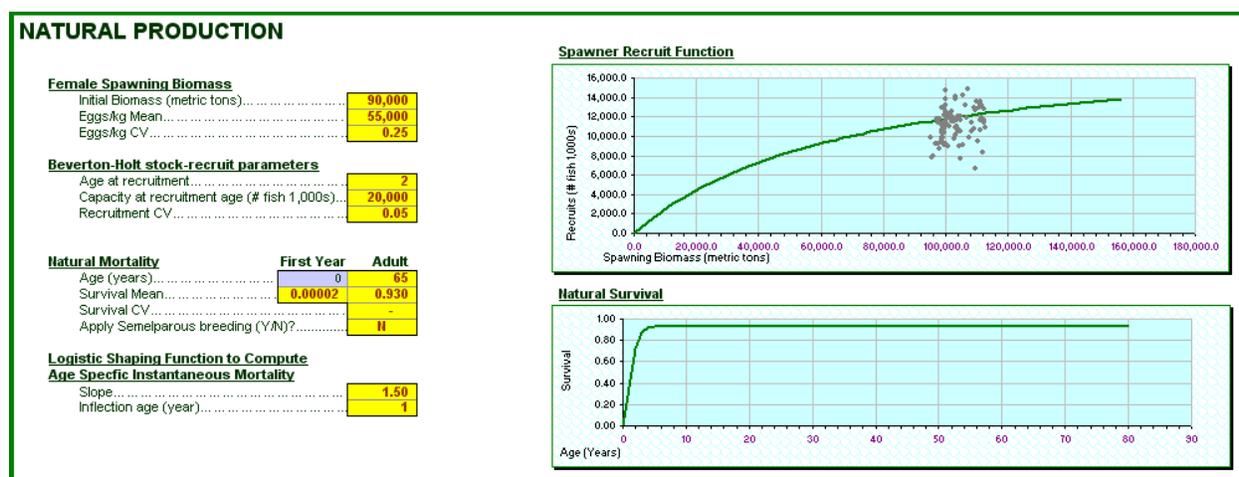
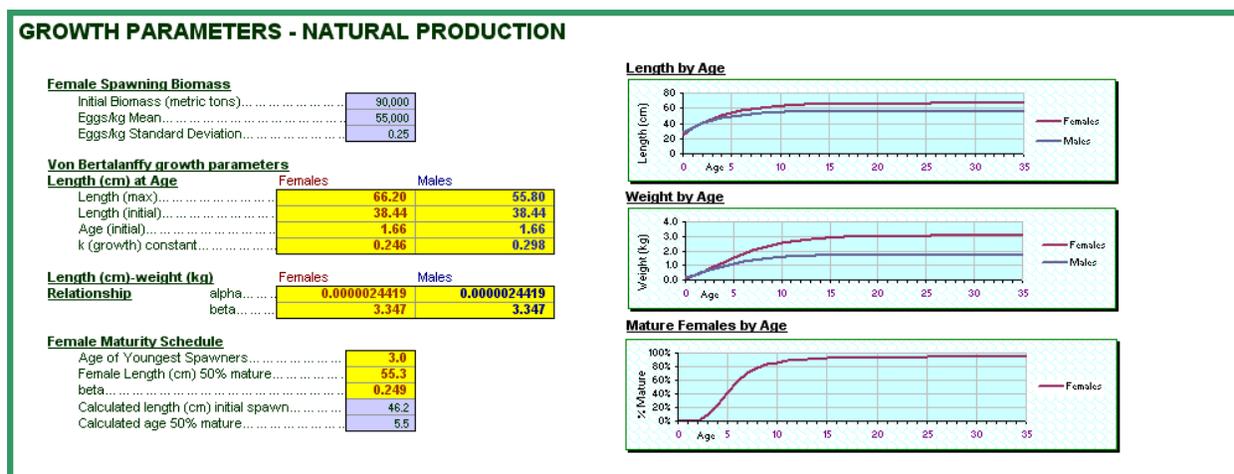


Figure 65. Natural Growth Parameters Module



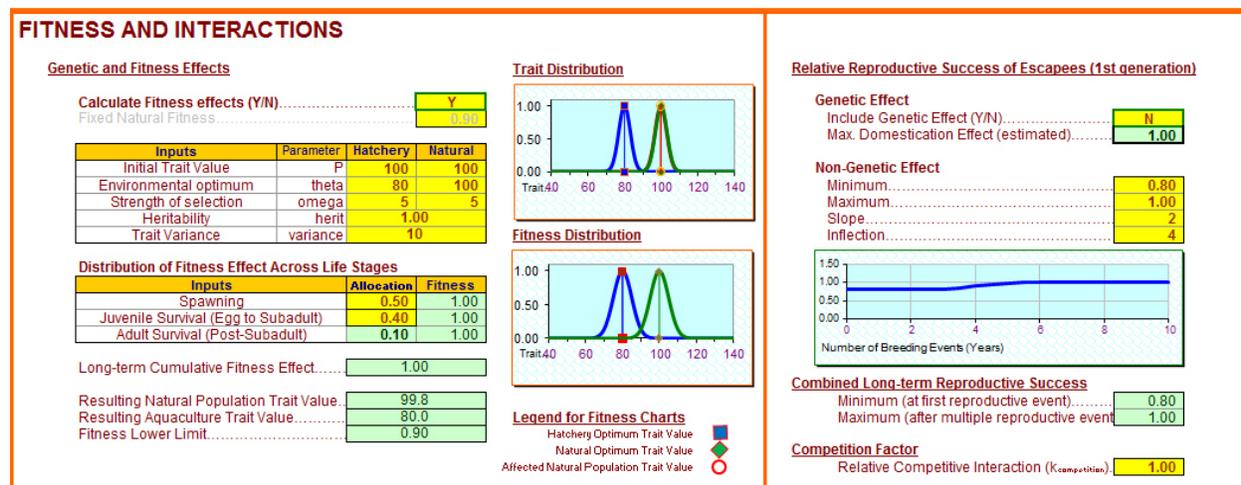
## Fitness and Interactions

The Fitness and Interactions Module is shown in Figure 66. The user has the option to calculate fitness effects based on trait values and strength of selection of farmed (hatchery) and natural fish, or to specify a fixed value for natural fitness across a 100-year time span.

The distribution of fitness effects across life stages allocation across the three inputs must sum to 1. Adult survival (Post-Subadult) is calculated based on the parameter values of the other two inputs.

The user can specify whether the relative reproductive success of escapees includes a genetic effect. If set to Y (Yes), the genetic and fitness effects parameters are included in the calculations for the maximum domestication effect and the combined long-term reproductive success of escapees.

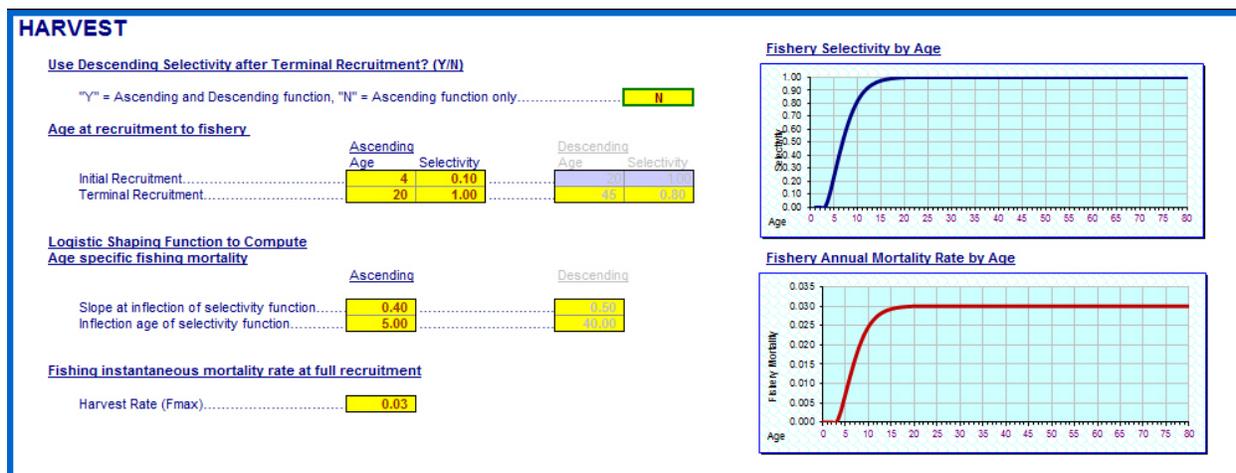
Figure 66. Fitness and Interactions Module



# Harvest

The Harvest Module contains parameters and shaping functions related to fishery selectivity and mortality (Figure 67).

Figure 67. Harvest Module

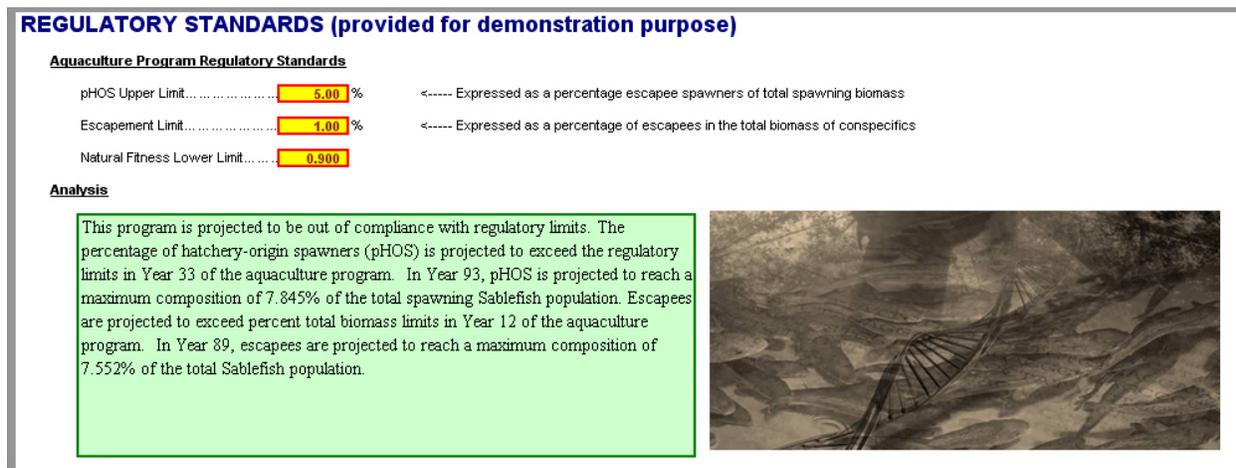


# Regulatory Standards

The Regulatory Standards Module is provided for demonstration purposes to facilitate discussion about plausible regulatory standards for escapes from aquaculture. Potential standards were explored in the development of the model including pHOS Upper Limit, Escapement Limit, and Natural Fitness Limit (displayed as heavy dashed lines in Figures 38, 39, and 42; header chart figures 2, 3, and 6). The module includes an analysis narrative, shown in Figure 68, which describes calculation results relative to standards.

This module is only included to help users visual outcomes relative to these limits and compare across scenarios. They do not represent any endorsement of a particular standard for escapes.

Figure 68. Regulatory Standards/Guidance Module



## Results Tables

The results tables display average, maximum and minimum calculated output values based on the range of years specified in the module. Some values will auto-update when changing the range of years, others will not. For accuracy it is recommended that OMEGA recalculate these results (*Apply* or *Run New Simulation*) when changing the Begin Year or End Year values.

## Scenarios (Load/Save)

The Scenarios Module is discussed in detail in the Using the Scenarios Module section beginning on Page 69.

## Settings/Preferences

The Settings/Preferences Module contains user preferences for display, calculation, and save settings. The default settings will likely not need to be changed in most cases, but the option is available.

## Help

The Help Module contains some basic reminders and some of the quick key combinations that are helpful while using OMEGA.

## Ending an OMEGA Work Session

Users should save the OMEGA file often during a work session and at the end of a work session. This is especially true if new species were added or scenarios were created or updated during the session. If desired, this can be handled automatically by setting the *Autosave on Close* value in the Settings/Preferences Module to *TRUE*. Alternatively, a user can save the Excel file by activating the Excel ribbon and saving the file via the typical Excel File Save or Save As functions from the ribbon. The ribbon can be activated or hidden by typing Ctrl-M.



# Troubleshooting

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Described below are some errors that were encountered during trial runs of OMEGA that seem to originate from the Windows operating system or the Excel program. These can be often corrected by the user as described below.

## **The OMEGA welcome message does not appear.**

– or –

### **When a button in the Header Section is pressed, nothing happens.**

The security settings in Excel may need to be set to “Enable content” in order for OMEGA module code to run. Please see the Macro Security Levels in Excel section for more information.

There have been a few cases where transfer of the OMEGA file via email has deactivated the OMEGA code modules in Excel. This is most likely a result of email security settings. The modules may have been deactivated if the welcome screen and/or security message do not appear and the Excel Trust Center security settings are set to *Activate with Notification*. The best solution to the problem is to contact ICF for a new version of the model.

### **The Load Scenario dialog does not disappear after the windows hourglass indicator turns back into a normal arrow indicating processing is complete.**

Under certain configurations we have noticed some display issues when running the model with an external overhead projector. It seems that sometimes the hardware display settings cause the OMEGA/Excel application to not close a form. This is a minor and unpredictable windows bug. If this occurs then click cancel to hide the form. This will not affect the calculations.

### **An error message related to forms appears (usually error #1004) when loading a scenario into OMEGA.**

This is another example of an error or bug that can happen unpredictably when OMEGA is used with an overhead projector. Click End on the error message and try again to load a scenario. If the error persists, close OMEGA, reopen and try again to load a scenario. This tends to be a temporary and random error that is not repeated when going through the same order of operations.

### **The program is encountering other issues that are not described above.**

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